W. F. Christmann
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A TREATISE

ON

ORE DEPOSITS

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BY

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SECOND EDITION

REWRITTEN AND GREATLY ENLARGED

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PREFACE TO THE FIRST EDITION

THE literature of metalliferous deposits, in the English language, is by no means inconsiderable. Numerous valuable disquisitions have at different times been published either as separate works or as communications to scientific journals, but the only general and systematic treatise on the subject which has appeared in English is a translation of Von Cotta's *Lehre von den Erzlagerstätten*, by Mr. Frederick Prime, published at New York in 1870.

Since that date much valuable information upon this subject has been accumulated, and the investigations of Daubrée, Daintree, Sandberger, and others have within the last few years thrown much additional light upon the genesis of metalliferous deposits.

The present work, which includes the results of the most important recent investigations, is divided into two parts. In the first, ore deposits in general are described and classified, while, in the second, examples are given from the principal mining regions of the old and the new world. In this portion of the work many remarkable metalliferous deposits of both ancient and recent formation are described, while, as a means of forming a standard of their comparative importance, copious statistics of production are furnished. Wherever exact information on this subject has been available, tabulated statistics of the yield of the principal ore-producing countries have been supplied. This appears to be the only way of accurately expressing the relative importance of different metalliferous regions, and care has been taken to collect information from trustworthy sources only.

During the preparation of a portion of the work I have had the assistance of Mr. B. H. Brough, Associate of the Royal School of Mines, and formerly student at the Mining School of Clausthal. For a period extending over several months, Mr. Brough was occupied in collecting statistical and other information from various foreign sources, and I am further indebted to him for numerous useful suggestions with regard to the arrangement of the matter, and for the careful attention which he has bestowed upon the work while passing through the press.

The greatest care has been taken to insure accuracy throughout the work, and the author hopes that but few mistakes will be found in it; although, in collecting such a large number of facts from so many different sources he cannot expect to have entirely escaped falling into error.

The Illustrations are from the pencil of Mr. Frank Rutley.

KENSINGTON, *July*, 1884.

PREFACE TO THE SECOND EDITION

When I commenced the task of preparing a new Edition of Phillips's well-known work, I did so with a full perception of the many difficulties that beset the undertaking. Whilst on the one hand, I had to deal with a book that had made for itself a world-wide and a well-deserved reputation, upon the other, its subject has within the twelve years that have elapsed since its publication, undergone such extensive changes, both material and theoretical, that it became obvious that simple re-editing was out of the question. I accordingly determined to introduce such modifications as, it seemed to me, Phillips himself might have done, had he been privileged to witness the newer developments of the subject which he did so much to advance.

The two parts into which the book is divided required very different treatment. The first, or theoretical part, which deals with the classification and genesis of ore deposits, had to be entirely re-written in accordance with modern ideas, a very great deal of work having been done on this subject in recent years, although but little of it has originated in this country. In the records of our Geological Society, communications treating of the geology of ore deposits are conspicuous but by their absence, nor have we in England any journal which, like the *Zeitschrift für Praktische Geologie,* is devoted especially to this subject; we have not even a word or a phrase, answering to the German *Montan-geologie,* to designate this particular branch of geology. It is a curious reflection that the neglect of the scientific study of ore deposits should coincide with the marked decadence in their practical working which we have to deplore in this country, and it is a fair matter for surmise how far these two facts may have reacted on each other as cause and effect. In other countries, however, and especially in Germany and America, the theory of ore deposits has received its due share of attention, and it is from the literature of these two nations that I have drawn most of the material for this part of the work. I have, however, endeavoured to adhere as closely as I possibly could to the original lines laid down by the author.

At the time when the original work was written, the brilliant and fascinating theories of Sandberger had just seen the light, and Phillips seems to have been greatly swayed by them, more so, no doubt, than he would have been were he writing at the present day with the knowledge that the labours of succeeding investigators had been far from confirming these theories in their integrity. I do not pretend to have put forward any new theories on this subject; I have merely attempted to summarise as fairly as possible the views held by the various schools of thinkers, and to reconcile and combine them as far as might be into one approximately coherent system, whilst yet at the same time retaining the original form, and where possible the language, of the author's work. Influenced very greatly by the latter consideration, the result has naturally been a compromise far from satisfactory to myself, though I feel bound to take upon my own shoulders the responsibility for the whole of the first part as it now stands.

With regard to the second part, the case was different. This part is, in the main, a record of facts and observations, and I have erased but little, except in the rare cases where the results of more extended operations have clearly disproved earlier conjectures about certain deposits. I have been mindful of the especial value that attaches to observations underground, because in mining, fresh phenomena can only be revealed by the obliteration of those previously discovered. I hold that past mining records must be treated with more than ordinary reverence, for, once lost, they can never be restored. I have, therefore, left the descriptions of mines and mining districts practically intact, and have done little more than add the results of more recent studies, and insert accounts of such fields and deposits as have either been further developed, or newly opened up, since the original edition appeared, the list of such being a sufficiently formidable one, and including many that are to-day of the greatest importance.

I fully endorse the opinions held by Phillips on the value of mineral statistics, and have throughout preserved those of the original work, merely supplementing them with the most recent reliable figures obtainable, in almost every case from official sources. I venture to hope that these will be found as accurate as mining statistics can be expected to be.

To attain even the degree of completeness that has been reached in the present volume would have been practically impossible without the generous assistance that I have received from friends and correspondents in all quarters of the globe, which assistance I have the greatest pleasure in herewith gratefully acknowledging.

HENRY LOUIS.

NEWCASTLE-UPON-TYNE.
August, 1896.

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PART I

ORE DEPOSITS IN GENERAL

Metals which occur in a state of approximate purity are said to be *native*, and when two or more such metals are found in combination the substance is called a *native alloy*. Usually the metals sought after by the miner are, however, not found in the native state, but are mineralised by being united with various non-metallic bodies. In this way they combine with sulphur or chlorine, giving rise, respectively, to metallic sulphides or chlorides; with oxygen the metals form oxides, and with acids they yield salts, such as carbonates, sulphates, and phosphates.

All natural combinations of a metal with such mineralising substances are called *ores* when the proportion of metal which they contain, after suitable mechanical preparation, is sufficiently large to admit of their being advantageously treated by the metallurgist. Although perhaps not strictly correct, any material obtained by mining that contains a workable proportion of a metal is often called an ore, even if the whole of the metal be present in the native state.

Ores of the different metals are sometimes found in surface deposits, disseminated through igneous and sedimentary rocks, in more or less regularly stratified or bedded formations, in detached masses, and, above all, in *veins* of various descriptions. The non-metalliferous minerals forming part of the latter are known as the *matrix*, *gangue*, or *veinstone*. Metalliferous minerals are found in rocks of every geological age; but they occur most frequently in mountainous districts, and in the older rocks, especially near the junction of igneous rocks with those of sedimentary origin. They are also frequently met with in strata which have either been penetrated by eruptive dykes, or have been subjected to extensive metamorphic alteration. The ores of each of the different metals are, however, often restricted within certain geological horizons, beyond which they seldom occur in remunerative quantities.

Gold, platinum, and tin ore are found in alluvial detritus, in which they evidently were not formed by chemical action, but have resulted from the disintegration of older deposits, whose constituents have been removed and re-arranged by the mechanical agency of water.

The fragments constituting these superficial deposits are usually much water-worn, and the associated metals or metalliferous particles are mainly concentrated in particular areas, over which water has flowed with great activity. Metalliferous deposits of this kind are usually of comparatively recent date, and are generally not older than the Tertiary period, but are known of various ages, as ancient at any rate as the Carboniferous formation. Localities in which alluvial detritus is washed for gold are known as *placers*, but when tinstone is the ore sought after, they are called *streamworks*.

The ores of iron and manganese are almost the only metalliferous minerals usually occurring as stratified beds, those of nearly all the other metals being obtained from some other variety of mineral deposit.

Although aluminium and magnesium are now regularly produced upon a commercial scale, they can scarcely be classed among metals derived from metalliferous ores, in the sense in which that term is usually understood. The same may be said of sodium, which is chiefly employed in the preparation of the two above-mentioned metals.

The miner like the metallurgist uses the word metal in a conventional, not in a chemical sense, and restricts its meaning to that of "heavy" metal, excluding therefore such metals as the above and those of the alkalies and alkaline earths generally, and including only the more ordinary metals of commerce, namely, gold, silver, platinum (and the platinoid metals), mercury, copper, bismuth, antimony, arsenic, lead, tin, nickel, cobalt, chromium, iron, manganese, and zinc. It may be noted that these metals and their ores are all objects of commerce, although some, like cobalt and arsenic, are not employed at all in the arts in the metallic state, and others, like manganese and chromium, only when alloyed.

The Classification of Ore Deposits.

Metalliferous deposits are found in such varying forms and under such differing circumstances that the subject of their classification is beset with the gravest difficulties. Various writers have proposed systems of classification, all of which may, broadly speaking, be reduced in principle to two: the morphological and the genetic. The former method, which groups together mineral deposits in accordance with their form and structure, is obviously more or less empirical, and at best can only be looked upon as a convenient provisional aid to their study, whilst the latter, which, if perfect, would give us a true natural system, is rendered so difficult as to be all but impossible in the present state of our ignorance respecting the true mode of origin of these deposits; widely different theories on most points connected with the formation of ore deposits have been put forward by the principal writers on the subject, and none can yet be considered as having been definitely adopted, although the labours of various observers have enabled us to reject not a few. At the best, however, any genetic classification must be but tentative, and it becomes a question whether it is preferable to rely upon a wholly empirical mode of division, that may bring together in the same group deposits of really different origin and nature, or whether it is better to attempt an imperfect natural classification, in the hopes that it may gradually be perfected by the labours of successive workers, or whether again, a compromise between the two systems cannot be adopted, that may preserve the advantages to some extent, of simplifying the study, whilst it does not quite ignore the natural relations of ore deposits. The latter is the principle that will be attempted in the present volume.

To catalogue the various classifications that have been proposed by the very numerous writers on this subject would occupy far too much space, and would serve no useful purpose.

The systems of a few, typical more or less of the rest, will be given here, rather with the object of showing how the subject has been attacked and in what directions it has developed than with that of presenting anything like an exhaustive history of it.

The morphological system has been followed by many writers ; one of the earliest was Waldung von Waldenstein (1824), who divides ore deposits into tabular deposits, stock deposits, and scattered masses.

Von Cotta[1] goes somewhat further, and institutes the following divisions :—

I. *Deposits of regular form.*

1. Beds.
2. Veins.

II. *Deposits of irregular form.*

1. Masses (stockworks, contact masses, fillings of cavities).
2. Impregnations.

Grimm,[2] ten years later, followed much the same general plan, except that he attached more importance to the distinction whether the metalliferous ores occur disseminated through a rock or more or less concentrated into a deposit, his classification being the following :—

Division I. Impregnations; disseminated in rocks.

Subdivision 1. Original.
Subdivision 2. Secondary.

Division II. As subordinate members of strata or in definite deposits.

Subdivision 1. Tabular deposits.
A. Beds.
B. Veins.
C. Tabular segregations.

Subdivision 2. Irregularly shaped deposits.
A. Bedded masses.
B. Pockets, &c.
C. Stockworks.

[1] *Die Lehre von den Erzlagerstätten*, 1859.

[2] *Die Lagerstätten der nutzbaren Mineralien*, 1869, p. 14.

Callon in his lectures on mining reverts to three divisions only, veins, beds, and masses. The most recent writer on this subject, C. Le Neve Foster,[1] uses the same classification and separates mineral repositories into

Tabular or sheet-like	1. Beds. 2. Veins.
Non-tabular	3. Masses.

Other writers have employed systems based on morphological distinctions with the assistance of genetic characteristics, and in these systems sometimes the former and sometimes the latter principle is found to prevail. Lottner-Serlo[2] inclined to the first named method, and employed the following classification :—

A. Included Deposits.

- I. *Tabular deposits.*
  - *a.* Veins.
  - *b.* Beds and seams.
- II. *Massive deposits.*
  - *a.* Irregular masses.
  - *b.* Stockworks.
- III. *Other irregular deposits.*
  - *a.* Bunches.
  - *b.* Pockets.
  - *c.* Reniform bunches.

B. Superimposed Deposits.

- IV. *Alluvial (débris) deposits.*
- V. *Superficial deposits.*

A. von Groddeck[3] has used a somewhat similar system, but has given more weight to genetic considerations:

A. Original Deposits.

Formed contemporaneously with the containing rocks.	I. *Stratified deposits.* 1. Massive ore-beds. 2. Segregated deposits. 3. Stratified ores. II. *Massive deposits.*

[1] *A Text-book of Ore and Stone Mining*, 1894.
[2] *Leitfaden zur Bergbaukunde*, 1868.
[3] *Die Lehre von den Lagerstätten der Erze*, 1879.

Formed subsequently to the containing rocks.	III. *Filling cavities.* 1. Filling fissures. *a.* In massive rocks. *b.* In stratified rocks. 2. Filling hollows. IV. *Metamorphic deposits.*

B. FRAGMENTARY DEPOSITS.

In a subsequent paper on the same subject,[1] he critises the various systems employed up to that time, and points out with much force that his group B is really a subdivision of I, and that his system is therefore reducible to four groups only :

I. Stratified (or sedimentary) deposits.
II. Massive (or eruptive) deposits.
III. Deposits filling cavities.
IV. Metamorphic deposits.

He however recognises in this paper that metasomasis plays an important part in the formation of ore deposits and suggests that it may be necessary to make a fifth class of metasomatic deposits. Von Groddeck seems fully alive to the difficulties of the problem, and points out that metasomatic or epigenetic deposits are often intimately connected with fissure veins, as for instance when a fissure in granite filled with tin-bearing gangue is accompanied by a partial decomposition of the granite, resulting in the deposition of tinstone disseminated throughout the rock, or when a hollow in limestone, filled with iron ore or calamine, is accompanied by a transformation of the surrounding limestone into these ores.

This paper constitutes a distinct advance in the study of the classification of mineral deposits, and embodies important developments of the genetic principle, thus forming an appropriate introduction to more modern methods.

Purely genetic methods have only been elaborated in recent years ; notably by H. S. Monroe[2] and H. F. Kemp[2] in the United States, and by F. Pošepny,[3] on the Continent. Not one of these is completely satisfactory, but it will be interesting to collate the

[1] "Bemerkungen zur Classifikation der Erzlagerstätten," *Berg. u. Hütt. Zeit.*, 1885, p. 217.

[2] J. F. Kemp, *The Ore Deposits of the United States*, New York, 1893, p. 52.

[3] F. Pošepny, "The Genesis of Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, xxiii. 1893, p. 197.

latter with one of the former, more especially as they appear to have been evolved quite independently of each other. Kemp's system seems to be an elaboration of Monroe's, and though scientific, is too cumbersome for ordinary use.

Monroe's classification of mineral deposits is the following :—

I. *Of surface origin, beds.*
- *a.* Mechanical.
- *b.* Chemical.
  1. By evaporation.
  2. By precipitation.
  3. Residual deposits from solution of limestones.
- *c.* Organic.
- *d.* Complex.

II. *Of subterranean origin.*
- *a.* Filling fissures and cavities formed mechanically.
  1. Fissure veins, lodes.
  2. Cave deposits. } The cavities of 2 and 3 are enlarged by solution of limestones.
  3. Gash veins. }
- *b.* Filling interstitial places and replacing the walls.
  1. Impregnated beds.
  2. Fahlbands.
  3. Stockworks.
  4. Bonanzas.
  5. Masses.

Pošepny's classification :—

1. *Ore deposits in spaces of discission.*
   - *a.* Ore veins in stratified rocks.
   - *b.* Ore veins in the neighbourhood of eruptive masses.
   - *c.* Ore veins wholly within large eruptive formations.
2. *Ore deposits in soluble rocks.*
   Fillings of spaces of dissolution and metasomatic deposits.
3. *Metamorphous deposits.*
   - *a.* Ores in distinctly stratified rocks.
   - *b.* Metasomatic deposits in soluble rocks.
   - *c.* Deposits in crystalline schists and eruptive rocks.

4. *Hysteromorphous deposits.*
   a. Chemical effects.
   b. Mechanical effects.
   c. Hysteromorphs of older geological formations.

It will be noticed that Monroe includes mineral deposits of all kinds, whether metallic or not, within his system, whilst Pošepny has considered ore deposits alone; hence it is that some classes in the former, *e.g.*, I*b*1 and I*c*, are not represented in the latter system. Monroe's I pretty nearly corresponds to Pošepny's 4; the former's II*a* is the latter's 1 and part of 2 apparently; the former's II*b*1 is the latter's 3*a*, and the remaining portion of the former's II*b* seems to be approximately included in the latter's 3*b* and *c*. Pošepny has worked upon more strictly genetic lines than has any other writer on this subject, but he has naturally followed his own theories of the mode of formation of ore deposits; he has laid more stress than any one before him on the importance of metasomasis (a convenient word introduced by Stelzner to signify the complete change of rocky matter into ore by the chemical replacement of one or more of its constituents), the influence of which action in the production of ore bodies is becoming more distinctly recognised. A comparison of these two last systems shows in the clearest way the difficulties that beset purely genetic classification; whilst all our theories on this subject are in a transition state, whilst the most conflicting views are advanced by authorities entitled to the utmost respect, and whilst no one has as yet succeeded in explaining the mode of formation of the simplest mineral deposit in such a way as to be beyond the reach of destructive criticism, it is perhaps best to avoid basing a system of classification entirely on theories that may at any moment be destined to undergo demolition, and to rather employ morphological characteristics to a considerable extent, whilst giving due value to such genetic principles as are pretty generally accepted. It is moreover indisputable that one and the same deposit may have owed its origin in different parts to different causes, and would therefore on purely genetic grounds be classed in two different groups. Thus a deposit of ore may fill a cavity produced in places by mechanical action (by discission) and in other parts formed by solution (by erosion). It is indeed difficult to conceive of a cavity formed entirely by solvent action unless the solution found in the first place a fissure through which it could travel so as to enable it to exert such action, whilst on the other hand every fissure through which a current of water is moving must have its walls more or less dissolved away thereby. The formation of ore deposits has in all probability been a highly complex process, such as would with difficulty admit of any simple classification. Again, seeing that in many deposits there are two separate stages to be considered—firstly, the formation of the cavity, and secondly, the the filling up thereof with the ore matter—a double system of classification with its attendant complications seems inevitable if all modes of occurrence are to find their separate places in it.

At the same time it must not be forgotten that the main object of classification is, after all, to assist the practical miner, and if possible, to guide him in his exploitation of mineral deposits. If it were possible—as it may be some day—to indicate from *a priori* theoretical considerations, what parts of a deposit are likely to be the most valuable, or in what directions the researches of the miner and prospector ought to be prosecuted, there would then be a very strong argument in favour of basing a classification on genetic principles. Meanwhile, in the present state of our knowledge, we are quite unable to do anything of the kind.

The shape of a deposit is the most important factor in determining the method of exploitation that will be best adapted to its economical working; that this is the case is sufficiently obvious from the very broad distinction made by practical men between lode-mining and bed-mining, methods which differ so widely from each other that their very technical phraseology is utterly different.

Any efforts to advance a purely technical art like mining must place practical considerations in the first place, and must subordinate theory to a very great extent to practical requirements. Morphological conditions must accordingly still be given their due weight in any system of classification, for the latter to be of any practical value.

The following system will accordingly be adopted in this volume, not with the belief that it is in any sense a perfect one, but simply as a provisional method that can be applied practically, whilst it does not altogether lose sight of the probable origin of the various classes of deposits. At best it is only a compromise, and as such cannot but have all the defects that are inherent in compromises:—

Class I.—Symphytic Deposits.[1]

Group *a.* Clastic deposits.
Group *b.* Precipitates from aqueous solution.
Group *c.* Deposits from solution, subsequently metamorphosed.
Group *d.* Disseminations through sedimentary beds.

Class II.—Epactic Deposits.

Subclass 1. *Veins.*

Group *a.* Fissure veins.
Group *b.* Bedded veins.
Group *c.* Contact veins.
Group *d.* Gash veins.

Subclass 2. *Masses.*

Group *a.* Stockworks.
Group *b.* Massive deposits in limestone.
Group *c.* Massive deposits connected with igneous rocks.
Group *d.* Disseminations in igneous rocks.

[1] The following was the classification adopted by Phillips in his original edition :—

I. Superficial.
- *a.* Deposits formed by the mechanical action of water.
- *b.* Deposits resulting from chemical action.

II. Stratified.
- *a.* Deposits constituting the bulk of metalliferous beds formed by precipitation from aqueous solutions.
- *b.* Beds originally deposited from solution, but subsequently altered by metamorphism.
- *c.* Ores disseminated through sedimentary beds, in which they have been chemically deposited.

III. Unstratified.
- *a.* True veins.
- *b.* Segregated veins.
- *c.* Gash veins.
- *d.* Impregnations.
- *e.* Stockworks.
- *f.* Fahlbands.
- *g.* Contact deposits.
- *h.* Chambers or pockets.

I have rejected this grouping for the one given above for various reasons. In the first place, either the superficial deposits should be classed as a division of the stratified, because they really are stratified, or else deposits ought to be divided first of all into two main groups, the superficial and the deepseated (*vide* "Bemerkungen zur Classifikation der Erzlagerstätten," A. von Groddeck, *loc. cit.*). Of these two alternatives, the former appears to be the more logical because the mere fact of a deposit being at the surface or buried beneath say some hundreds of feet of eruptive rocks, *e.g.*, the deep leads of Victoria or California, does not seem

Class I.

Symphytic Deposits.

This class is characterised by the fact that all the ore deposits included in it have been formed contemporaneously, in a broad geological sense, with the enclosing rocks; that is to say, they are original members of the strata among which they occur, being always more recent than the rocks upon which they rest, and older

to constitute a distinction of sufficient importance to warrant a division based upon it.

Further, I do not like designating an important group like III. by a negative distinction. Among the subdivisions of that group I have made a few alterations; I have substituted the word "bedded" for "segregated" in *b*, because the latter implies a mode of origin which is not in all cases the true one for this class of deposits. For the same reason I prefer "disseminations" to "impregnations."

I hold that the term segregation should be restricted sharply to those cases in which separation has occurred out of a fluid, semi-fluid or plastic mass, or at any rate, out of a mass, the particles of which were sufficiently mobile to admit of their rearrangement; it would thus be practically equivalent to the "magmatic differentiation" of Vogt. To take an example, a narrow veinlike body of felspar in a mass of granite is not infrequently met with. It may have been produced by the formation in the first place of a fissure—a contraction fissure, perhaps, or one due to dynamic movements—in the solid granite, and the subsequent leaching of the felspar out of the rock by the action of heated waters and its deposition within the crevice. Or again, before the complete solidification of the granite, whilst crystallisation was still going on, a certain quantity of felspar, separating out of the main rock-mass, may have coalesced to form a tabular mass, there being no doubt that such a tendency to aggregation exists. The former is an example of the mode of formation of a vein, the latter of that of a segregation deposit, and it is to deposits formed in this way that I propose to confine the term.

I have omitted *f*, fahlbands, because I cannot but regard this as a local modification of fissure veins which has many analogies even though but few counterparts in other districts.

I have, with some misgiving, altered contact deposits to contact veins, because their form is generally veinlike, and their origin often, if not always, connected with the existence of a fissure or a plane of weakness at the junction of the rocks.

Finally, I have divided *h*, pockets, into two separate classes, according to their occurrence either in soluble rocks or in igneous ones, in which their mode of origin must have been radically different. I have not ventured on any more drastic changes, partly for the reasons stated in the text and partly because I was anxious to preserve as far as possible the arrangement of the original work, whilst bringing it into line to some extent with modern ideas.

I have ventured to name the two chief classes of deposits respectively *symphytic* and *epactic*, the first being such as were formed simultaneously in a geological sense with the surrounding rock, whilst the second have been introduced subsequently. I could find no convenient words in the literature of geology that quite expressed this distinction, and was therefore compelled to coin those here employed, derived from Greek words that were used by Aristotle to convey the antithesis here intended: "Ἡ δ' ὑγρότης, καὶ ἡ σύμφυτος, καὶ ἡ ἐπακτός," *De Generatione Animalium*, lib. iii. cap. i.—H.L.

than the rocks that overlie them. They are true stratified deposits, and are known as *beds* or *seams*. They are characterised by a position that approximates more nearly to the horizontal than to the vertical, by one dimension, usually the vertical, being far smaller than the two others, and by, generally speaking, great uniformity over comparatively wide areas.

Ore beds being thus stratified metalliferous deposits, interpolated between rocks of sedimentary origin belonging to every geological age, they lie parallel to the stratification of the enclosing rocks, and follow all their contortions. In this way ore beds form synclinals or *basins*, and anticlinals or *saddles*, of which the upper portions are often removed by denudation.

When a bed has been tilted from a horizontal position, its maximum inclination towards the horizon is called its *dip*, and the amount of this dip may be stated either in degrees, or by saying that it falls a certain number of feet or inches in a given distance. The line at right angles to the dip of a bed, which is consequently a horizontal line, is called its *strike*, and is described by its line of compass bearing, either true or magnetic; the former is to be preferred, although the latter, which has become consecrated by centuries of custom, is generally used by miners.

The line along which a bed cuts the surface of the ground is called the *outcrop* or *basset*, and this, where the surface is horizontal, will correspond with the strike. Under no other circumstances will this be the case unless the bed be truly vertical, or unless the surface of the ground, although inclined, forms a plane, whose trace is parallel to the strike of the bed; for all other inclinations the outcrop will wind around with the irregularities of the surface, the deflections becoming greatest where the dip is least considerable, and the inclination of the surface the most.

The layer immediately beneath a metalliferous bed is called its *floor*, while that which lies directly above it is its *roof*. The thickness of a bed is measured by a line perpendicular to its floor and roof. The thickness often varies considerably in different parts, and the bed may gradually thin out and finally disappear. In many cases there are no very sharp limits between a metalliferous bed and the enclosing rocks.

Like all other rocks, metalliferous beds are frequently divided by fissures; these are sometimes mere rents; but often there is not only a severance of the strata, but also a displacement of the rocks severed. In this way portions of beds which were originally continuous are found at very different levels on the opposite sides of a fissure, and hundreds of feet may intervene between the disunited portions of a bed once upon the same plane. In such cases the fissure is by geologists called a *fault*, and is known among miners as a *slip, slide, heave, throw, trouble*, or *check*. The amount of disturbance produced by a fault, measured vertically, is called its *throw*, and is often spoken of as an *upthrow* or a *downthrow*, according to the side from which it is approached by the workings of the miner. When the surface is horizontal its amount may be measured perpendicularly from the outcrop, but when this is not the case it is measured from an assumed horizontal plane. If a bed, where it is cut by a fault at *a*, Fig. 1, be 50 yards from the surface A B or from an imaginary horizontal line, and the other portion of the bed on the opposite side of the fault be at *b* 100

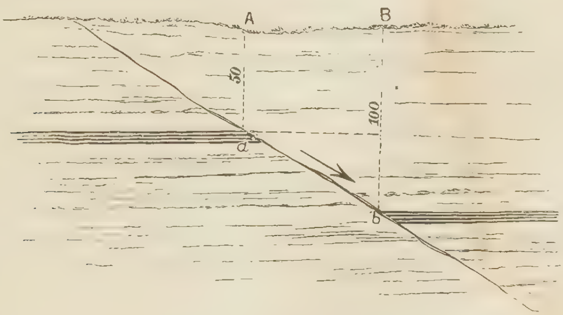


FIG. 1.—Section of a fault.

yards below the same line, the throw of the fault is said to be 50 yards without regard to the distance measured either horizontally from A to B or from *a* to *b* along the fault. When the outcrop of a bed is cut by a fault, the distance between the two parts of the broken bed, measured at right angles to its strike, is usually spoken of as the *heave* of the fault. The character of a fault is much influenced by the hardness and rigidity of the rocks traversed by it, while its effect mainly depends on the peculiarities of the beds through which it passes, with regard to their amount of dip and degree of contortion; the result is also much influenced by the direction and inclination of the fault itself.

When beds of a soft and yielding nature are traversed by a fault, the fissure is often bounded by two mere planes of division, the surfaces of which are frequently polished and striated by the friction to which they have been subjected. These polished surfaces are known under the name of *slickensides*, and occur most numerously in the neighbourhood of mineral veins, and in rocks which have been much subjected to disturbing influences. In some cases, although the planes bounding the fracture along

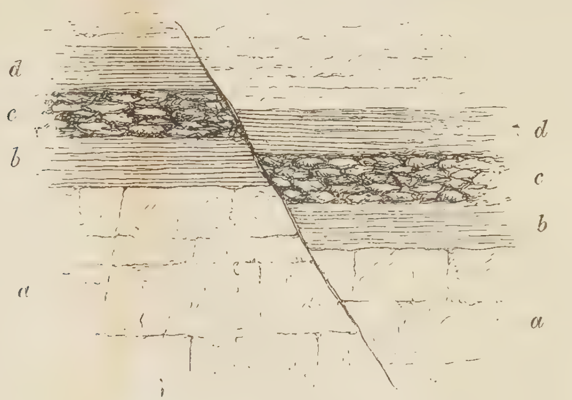


FIG. 2.—Beds faulted without distortion; section.

the line of fault may be apparently sharp and clean, the beds on either side are traversed by numerous subordinate slickensides, as though a tremulous grinding motion had been communicated to the beds for some distance.

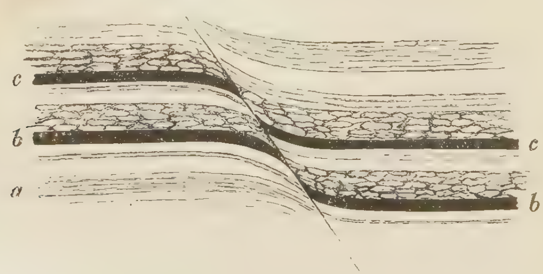


FIG. 3.—Beds distorted by a fault; section.

In many cases beds end abruptly at a fault without any kind of disturbance in their direction, as seen in Fig. 2, where the throw is measured by the vertical distance between the two portions of the beds *a*, *b*, *c*, or *d*, respectively. They sometimes, however, appear to have been, to some extent, distorted and bent out of their original position along the plane of fault. This bending of the beds usually occurs in the way indicated in Fig. 3, as might be anticipated from the supposed nature of the motion which has taken place, and they are then said to *dip to the downthrow* and *rise to the upthrow*. J. Beete Jukes states that he had frequently been told by coal miners that the reverse of this bending sometimes takes place, and that he had himself seen an example of this reversed flexure at the Himley Colliery, near Dudley, but was unable to explain its cause.[1] It is by no means a rare phenomenon in coal seams.

A series of parallel faults situated at short distances from one another sometimes traverse a district for considerable distances, and if the throws are all in the same direction, they break up the

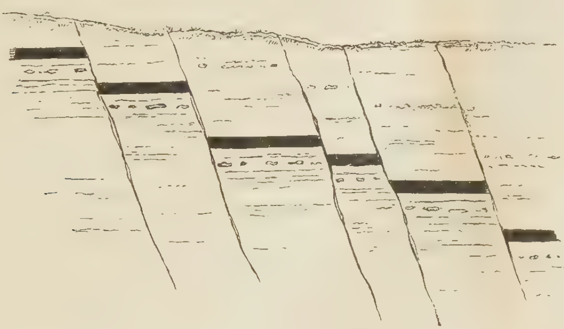


FIG. 4.—Diagram of step faults.

strata into a number of steps as shown in Fig. 4, forming so-called *step-faults.*

When any of the throws are in contrary directions, it is manifest that an irregular disruption of the beds must be the result. Two throws in contrary directions of about the same amount but of different ages produce what is known as a trough fault, in which a portion of the bed is, so to speak, depressed below the general level. This form is illustrated by Fig. 5. It has been suggested that in speaking of the inclination of faults, it might perhaps be better not to employ the term dip, as in the case of beds, but to adopt that of *hade* or *underlie*, were it not for the fact that miners generally use the terms hade and underlie in the sense of an inclination from the vertical. The underlie is the complement of the dip, which means the inclination from the horizon, and thus a plane which dips 60° will underlie or hade 30°. When, therefore,

[1] *The Student's Manual of Geology*, 3rd Edition, 1872, p. 201.

these terms are used, it is necessary that it should be understood in what sense they are employed. The word dip is always intended to express an inclination measured from the horizontal, while hade and underlie are employed to signify an inclination from the vertical.

Whether the formation of the fissure and the dislocation of the beds occurred simultaneously or not is a question that is still in many cases open to doubt; it is however convenient to examine the phenomena separately for the purpose of getting a clearer idea of their effects. The intersection of a bed by a fissure plane may be readily represented geometrically and treated as a simple problem in the intersection of planes; the direction and dip of this line of intersection is thus readily determined for any given

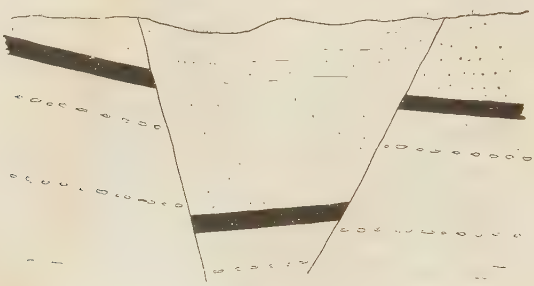


FIG. 5.—Diagram of trough fault.

case, once the directions and amounts of the dips of the two planes are known.

When dislocation has taken place in addition to fissuring, the direction of dislocation in *normal* faults is such that the portion of the bed that lies on the inclined plane appears to have slipped down relatively to the position of the other portion; thus in Fig. 1 the portion at *b* has slipped down relatively to the part *a*. It is not meant by this statement to suggest that the one portion has actually remained stationary whilst the other has sunk bodily; all that is implied is that the relative motion of the two portions of the bed has been such, that one portion *seems* to have slipped down upon the inclined plane formed by the fault fissure.

This is a point of immense importance in practical mining, because it furnishes a rule, applicable in the immense majority of cases, by which the miner may know in which direction to look for the faulted part of the bed; it forms the guide by which he judges whether he is dealing with an "upthrow" or a "downthrow" fault. The rule is often quoted thus: if in driving on a bed a fault is met with, if it is first met with in the roof, go down, if first in the floor, go up to find the faulted portion. The same rule is more tersely put in the phrase "To find the faulted part of a bed, follow the larger angle," but it is better expressed by saying that "a fault dips towards its downthrow." Assuming the motion to have been in the direction of the fissure plane parallel to the direction of its dip, which seems to be borne out by experience, it is evident that if the strike of the fault plane form an angle with the strike of the bed, any given point of the bed at the point of faulting will be moved in a direction forming an equal angle in plan with the dip of the bed; this direction can be resolved in the directions of the dip and strike of the bed, so that whether a level were being driven in the bed, or whether a heading were being driven to the full dip (the usual directions of driving in mining), the fault will appear to have displaced the bed vertically as well as horizontally, the amount of horizontal displacement depending not only upon the amount of throw of the fault, but upon the respective dips of the bed and the fault plane as well as on the angle between their lines of strike. When these last are parallel or nearly so, the fault is known as a *strike fault*, and there is no lateral displacement; a fault parallel or nearly so to the dip is called a *dip fault*. When a bed is horizontal, the strike of every possible fault may be said to be parallel to a strike of the bed, and hence there is no lateral heave; with a nearly horizontal bed, it will be so small that it may generally be neglected and the vertical throw alone be considered. This is very often the case in bed mining, but, as will presently be seen, in vein mining, where the deposits often lie at steep angles, the lateral dislocation plays a most important part.

Faults are sometimes perpendicular, and their throw is then not attended by any horizontal displacement; they are, however, much more frequently inclined, and when their throw follows the normal rule, it is clear that whatever may be the inclination of a fault, no part of any bed can be brought vertically beneath any other portion of the same bed, nor can any superior strata be brought immediately under those originally above them, unless in the unusual case of the bed dipping far more steeply than the fault. Exceptions to this normal fault rule occur in rare instances only; these exceptional instances, in which the bed is thrown in the direction of the smaller angle, or where the fault dips towards the upthrow side, are known by the name of *reversed*.

overthrust or *overlap faults.* A diagrammatic representation of such a fault is given in Fig. 6, where it will be observed that the beds on the right of the fissure must either have been forced upwards, or have remained stationary, while those on the other side were carried downwards along the line of fissure. Although the occurrence of reversed faults is decidedly exceptional, they are, nevertheless, occasionally met with.

The beds of auriferous conglomerate that are being so extensively worked on the Witwatersrand, Transvaal, South Africa, present numerous examples of overlap faults. One of these is shown in Fig. 7 taken from a coloured plate in Schmeisser's

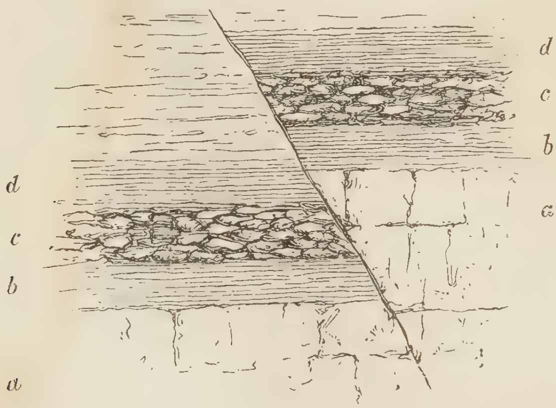


FIG. 6.—Diagram of reversed fault.

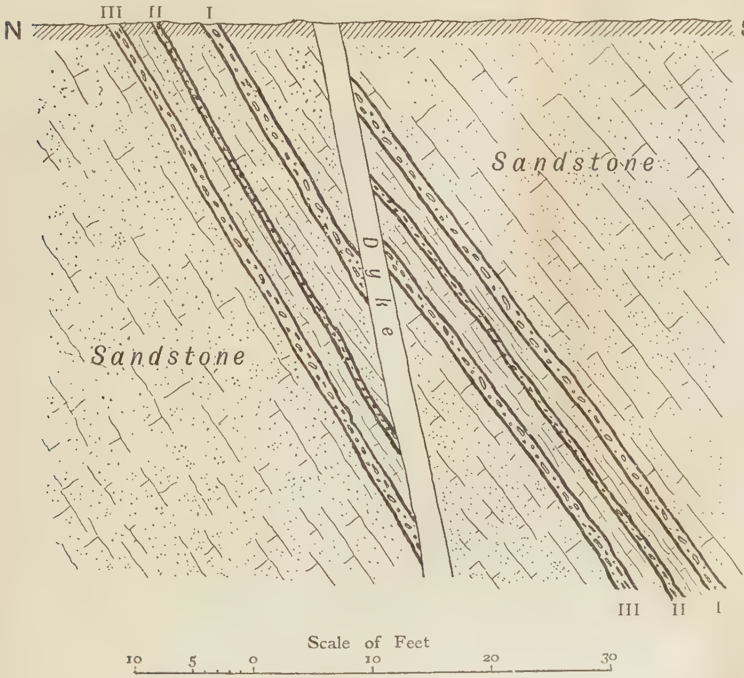
well-known work.[1] According to Hatch and Chalmers,[2] the beds are thrown up three successive times in the Langaagte Royal mine, a gain in auriferous ground amounting to 400 feet being produced thereby, whilst on the Witwatersrand Company's property the so-called "main reef" has a double series of outcrops some 400 feet apart owing to an overthrust fault.

It is manifest that when strata which have been much contorted are traversed by faults differing from one another both in dip and in direction, the changes in the relative positions of the beds will sometimes be of a very perplexing character. Moreover, both beds and faults have hitherto been treated here as if they were plane surfaces and as if the faulting movement were

[1] *Ueber Vorkommen und Gewinning der nutzbaren Mineralien in der Südafrikanischen Republik.* Schmeisser, Bergrath. 1894.

[2] F. H. Hatch and J. A. Chalmers, *The Gold Mines of the Rand,* 1895, p. 62.

strictly rectilinear. This is rarely the case in nature. The beds are nearly always bent or contorted, the fault fissure is often bent and twisted, and the motion of one part of the bed on the other shows generally more or less rotational or torsional movement combined with the rectilinear motion of translation, whilst the amount of movement varies in different parts of the same fault. A consideration of complicated examples of faulting would occupy more space than can be here devoted to the subject, but a careful



I. Main Reef. II. Middle Reef. III. North Reef.

Section through the May consolidated gold mine.

FIG. 7.—Section showing overlap faults at Witwatersrand.

study of such phenomena on the ground, having due regard to the foregoing general rules, should enable the observer to unravel all ordinary complications which may present themselves. We shall return to this subject later on under the heading of veins.

GROUP *a*. CLASTIC DEPOSITS, OR DEPOSITS FORMED BY THE MECHANICAL ACTION OF WATER.—These deposits have been produced by the degradation or disintegration of more ancient metalliferous deposits; they may result from direct weathering *in situ*, but have more often been transported and redeposited by the action of water. As a general rule they are nearly or quite superficial and of recent geological epochs, but ancient and deep-seated deposits are also known. The most important deposits of this class are those worked for gold and oxide of tin. These often consist of accumulations of sand and gravel formed on the banks of streams or the shores of lakes or seas, by the action of whose waters the aggregation of metalliferous *débris* has been effected.

In other cases, clastic metalliferous deposits represent the beds of ancient rivers, and are frequently of great thickness and of large extent.

Surface deposits of iron ore sometimes belong to this class, but have more frequently been produced by chemical action.

Placers.—In the case of auriferous quartz, and of the ores of metals distributed through a compact valueless matrix, it is necessary, before the metalliferous portions can be separated, that the veinstone should be more or less finely crushed by suitable machinery. The pulverised material is afterwards subjected to the action of water, so set in motion as to allow the heavier particles, by obeying the laws of gravitation, to fall to the bottom, while the non-metalliferous matrix is carried off in suspension. All auriferous sands and gravels have, on the contrary, been already pulverised and concentrated by a natural process of a similar kind, and it consequently only remains for the miner to separate the valuable from the valueless material either by re-washing alone, or by re-washing assisted by the use of mercury.

The most remarkable and extensive accumulations of auriferous gravels are probably those of California, where they are frequently of very considerable thickness, and extend over areas of many square miles on the Pacific slope of the Sierra Nevada.[1] These, which are sometimes known as *blue gravels,* were formerly believed to be of marine origin, but are now recognised as materials brought down by the agency of currents of fresh water from the mountains high above them and deposited, either in the beds of ancient rivers, or in lake-like expansions of such streams. This deposition of auriferous detritus generally took place during the latter portion of the Pliocene epoch, as is proved by the remains of animals and plants which it encloses, although some of these would appear

[1] J. D. Whitney, "The Auriferous Gravels of the Sierra Nevada of California," *Memoirs of the Museum of Comparative Zoology at Harvard College,* vi. 1880.

to exhibit certain Miocene relationships. This deposit of detritus was succeeded, throughout the whole extent of the Sierra, by an outbreak of volcanic activity, during which the auriferous drifts were, to a large extent, covered by deep accumulations of ash, pumice, and lapilli, which were finally overwhelmed by a general outpouring of lava. This capping of an almost indestructible material, sometimes above a hundred feet in thickness, has thus protected extensive areas of gravel which would otherwise have been swept away and which now form the "deep placers" or "deep leads" of the gold miner. The shallow placers, which were in places enormously rich, like the deposits at Carson's Flat, Melones Creek, &c., out of which immense fortunes were taken, are recent gravels deposited by streams still in existence and are of Quaternary age. It was mainly these deposits that determined the great gold rush to California in 1849.

The most important chemical change which has taken place in these deeper gravels subsequent to their deposition, is silicification, which becomes evident on examining the various organisms which are found embedded in them. The quantity of wood buried in these detrital masses is very large, and by far the greater proportion of the trees so found, has been converted into opal. These tree trunks sometimes bear evidence of having been worn by the action of the currents which bore them along together with the stony detritus in which they finally became enclosed. In some cases, fragments of wood are met with, which had been more or less completely converted into lignite previous to silicification. This partial conversion into lignite may often be observed in specimens in other parts of which direct silicification has taken place; so that the two ends of the same fragment may resemble, respectively, jet and opal. The transition from silicified wood to silicified lignite is, however, very gradual, although both often retain their original woody structure.

The analyses of specimens of silicified wood and silicified lignite on p. 22, made in duplicate by the author (J. A. P.), will serve to show the difference in their respective compositions.

Both specimens were obtained from the trunk of the same tree found in the auriferous drift under a volcanic capping, near Nevada city.

The results show that although all traces of organic matter have disappeared from the silicified wood, the silicified lignite still retains 14 per cent. of woody material. The gravels of which auriferous deposits are composed have in many instances

	Silicified Wood. Sp. gr. = 2·04.		Silicified Lignite. Sp. gr. = 1·95.	
	I.	II.	I.	II.
Water	5·77	5·80	4·41	4·46
Silica	92·43	92·26	80·04	79·82
Alumina	trace.	trace.	trace.	trace.
Ferrous oxide	·90	·88	·92	·87
Lime	·12	·18	·16	·16
Potash	·41	·37	·37	·30
Soda	·20	·18	·20	·22
Carbonaceous matter, &c.	—	—	14·06	13·92
	99·83	99·67	100·16	99·75

become firmly consolidated by a siliceous cement, and cases in which large transparent crystals of quartz have formed in the cavities between contiguous pebbles, are by no means unknown.

In addition to bones and teeth of the mastodon and of other extinct mammals, human remains, together with various rude works of art, are stated, on trustworthy authority, to have been discovered in these gravels. The remains thus found are supposed to include the celebrated Calaveras skull, which is stated to have been taken from the auriferous gravel at a depth of above 120 feet from the surface, and beneath a capping of dense black lava.

Among the works of art may be mentioned several curious stone implements found in the gravels under Table Mountain in Tuolumne county, covered by 150 feet of lava. These include stone spear-heads, many inches in length, mortars cut out of granite, and various stone scoops and ladles with well-shaped handles. The evidence on the subject appears to be now fairly established, and would lead to the conclusion that man must have existed in California in Pliocene times, and that he was contemporaneous with the mastodon and other extinct animals.

These beds of auriferous gravel, whether covered by lava flows or not, have yielded the bulk of the world's production of gold until quite recent times; in most of the world's important gold fields except in those of Russia, the production of reef gold is far more important now than that of alluvial, due to a great extent to the greater facility with which these beds could be worked, and to their very great local richness. The shallower deposits are now practically exhausted in most places, but the deeper lying beds are still of the greatest importance to the miner. They are usually worked by the process known as hydraulic mining, introduced about 1852. This consists in attacking the bank of auriferous material with one or more jets of water issuing from nozzles, sometimes six inches in diameter, which are connected by a column of wrought-iron pipes with a reservoir from 200 to 400 feet or more above the level of the discharge. In this way an enormous mechanical force is obtained, and the bank unless much consolidated by cement, is rapidly undermined and broken down. The water, with the disintegrated sand and gravel resulting from this operation, is conducted through large sluices provided with grooves or "riffles," into which mercury is introduced for the purpose of retaining the gold. This method of mining cannot, however, be applied except in localities where there is a proper fall for the sluice, and at the same time a sufficient depth below its outlet for the accumulation of the resulting rubbish or tailings. Every river flowing through the auriferou, belt of the Sierra Nevada, has acted as a natural sluice, the inequalities and the upturned slates of its bed taking the place of riffles for the retention of gold, derived not only from the immediate disintegration of auriferous outcrops. but also from the re-washing of older gravels. There will therefore be no difficulty in understanding the nature of the process by which a large amount of the precious metal has become concentrated within a comparatively limited space, and, consequently, that during the first two years after the discovery of gold in California, a vast majority of the miners were occupied on "river diggings." These naturally enriched accumulations having eventually become exhausted, it became necessary to attack the original, more abundant, but poorer, gravels lying at greater elevations above the valleys; and in order to do this with advantage, a cheaper method of working than had hitherto been employed was required. Such was the above-named hydraulic system of mining, and up to the present time a considerable portion of the gold contributed by California has been obtained from Pliocene and Miocene gravels. The enormous quantity of detrital matter thus annually washed down soon commenced to choke up the rivers, and in times of flood to be spread over the lower lying lands of California. The damage thus done to navigable rivers and to agricultural lands was so great that the large majority of the hydraulic mines of California were restrained from working by legal injunction, until in March, 1894, a bill, the so-called Caminetti Act, was passed by Congress to enable miners to work hydraulic claims, provided they impound their *débris*, under which arrangement hydraulic mining is once again coming into prominence in California.

It is remarkable that the auriferous gravels of Victoria are of approximately the same geological age as those of California; they, however, more frequently than in the latter country, represent the beds of ancient rivers once flowing through valleys which have subsequently been filled by the outpouring of volcanic matter. Victoria does not generally possess facilities for the employment of the hydraulic process, and the principal part of the placer gold found in that country is consequently obtained by mining beneath a capping of compact lava.

In consequence of the absence of marine Tertiary deposits in New South Wales, and the occurrence of a more complete series of strata in the Carboniferous formation, it is difficult to correlate precisely the gold deposits of that country with those of Victoria. It is, however, generally admitted that they occur in Tertiary strata, and are often of Pliocene age, although certain gravels which may be possibly Miocene, are also sometimes auriferous.

Several examples of still more ancient auriferous gravels can also be quoted; in addition to the Californian deep leads of Miocene age and the Quaternary placers, Mr. R. L. Dunn[1] describes certain beds of auriferous conglomerate of Cretaceous or Pre-cretaceous age on the Klamath River. In New Zealand gold-bearing gravels are described by H. A. Gordon[2] as being of Pliocene and Upper Miocene age on the West Coast of the South Island, of Lower Cretaceo-Tertiary age in the Nelson district, and of Devonian age in the same district, whilst in several places strata of secondary (Jurassic) age are reported to contain gold, but not in paying quantities.

C. S. Wilkinson, in the *Geological Survey Report* for 1876, drew attention to the occurrence of gold in ancient conglomerates of Carboniferous age, and similar occurrences are reported in both New South Wales and Queensland. Small quantities of gold were formerly collected near Bességes, Département du Gard, France, by washing a coarse-grained quartzose conglomerate of Lower Carboniferous age. Gold has also been proved to exist in minute proportions, but not in payable quantity, in the Carboniferous formation near Bristol.

One of the oldest auriferous conglomerates known is in the

[1] *Twelfth Report of the California State Mineralogist*, 1894, p. 459.

[2] "Hysteromorphous Auriferous Deposits of the Tertiary and Cretaceous Periods in New Zealand," *Trans. Amer. Inst. Min. Eng.*, 1895.

Black Hills of Dakota[1]; there a conglomerate of Potsdam age (base of Lower Silurian) rests upon highly metamorphic palæozoic schists, which are intersected by gold-bearing quartz veins, and is in turn covered by an overflow of porphyry. This conglomerate. which has been extensively worked, was very rich in gold in places, the gold occurring in smooth, rather flattened, rounded grains, showing all the characteristics of placer gold; a small nugget weighing 3 dwt. was found in it.

Nearly the whole of the gold produced in the Russian empire is obtained from placer washings, vein-mining being exclusively confined to the Ural Mountains, and is even there carried on upon a very limited scale, producing only about 7 per cent. of the total output of the empire. The gold-bearing alluvium of the Ural is sometimes a heavy clay, while in other cases it is made up of water-worn fragments of auriferous quartz, chloritic and talcose schists, serpentine, greenstone, &c. Some of the more important districts have recently been exhaustively studied by F. Pošepny,[2] who has described them with much detail.

Remains of various extinct animals occur deep down in these gravels, usually in the vicinity of the bed-rock. They include bones of *Elephas primigenius*, *Bos aurochs*, and *Rhinoceros tichorhinus*, which are likewise found in the gravels of western Europe. Some of the auriferous gravels of the Ural repose upon a water-worn bed-rock of hard highly-inclined crystalline limestone, believed to be of Silurian age; in other cases they lie on a talc schist, or on a soft granitic rock containing pyrites and but little mica, usually known as *beresite*. The two last-named rocks are traversed by veins of auriferous quartz.

Platinum generally occurs with gold in auriferous gravels, and is seldom found without that metal except at Tagilsk and Goroblagodatsk, in the Ural, where there is little or no gold. Platinum is obtained from placer diggings only, and has not been found to any considerable extent *in situ*, although grains of this metal are said to have been observed in the quartz of the mines of Beresovsk. In the districts in which platinum occurs unaccompanied by gold, the rocks in the neighbourhood of the deposits consist of serpentine and peridotite, while fragments of these rocks predominate in the sands and gravels. Chloritic and

[1] W. B. Devereux, "The Occurrence of Gold in the Potsdam Formation," *Trans. Amer. Inst. Min. Eng.*, 1892, p. 465.

[2] "Die Gold Districte von Berezov und Mias am Ural," *Archiv für Praktische Geologie*, ii. 1895, p. 499.

talcose schists, together with chrome iron ore, are to some extent present. From the constant occurrence of this metal in association with gravels mainly consisting of peridotite and serpentine, it is thought that platinum originally existed in the form of grains disseminated through these rocks. In addition to gold and chrome iron ore, platinum is often associated with iridium and iridosmine.

Among surface deposits resulting from the mechanical action of water are those streaks of titaniferous iron sand, often found on sea beaches along coasts largely composed of certain igneous rocks, The disintegration of such rocks liberates crystals of magnetite and of titaniferous iron ore, and these minerals being heavier than the felspar, quartz, &c., with which they are associated, become concentrated by the action of the waves. Large accumulations of black sands occur along the shores of the Bay of Naples, at Taranaki in New Zealand, between Point Mendocino in California and the mouth of the Umpqua River in Oregon, and particularly in Canada on the north shore of the St. Lawrence, from the Moisie River eastward. The ferruginous sands are here derived from the waste of the norite or labradorite rocks of the Upper Laurentian series, which are largely made up of labradorite and hypersthene, with magnetic and titaniferous iron ore, &c. At Mingan, Natasquan, and at several other points along the Labrador coast, iron sands occur under generally similar conditions. The production of cast iron from these sands is rendered difficult by their extremely fine state of division, but they have sometimes been advantageously employed for the direct production of blooms in the open fire.

On the Moisie River, charcoal bloomeries have been erected to work the iron sands, but not with much financial success, although excellent iron has thus been made. The high percentage of titanic acid, as shown in the annexed analysis by H. Louis, is a source of difficulty, nor does it yet seem that definite success has attended attempts to separate the magnetite grains from those of ilmenite by electro-magnetic separators.

Analysis of Moisie iron sands :—

Peroxide of iron	51·06	Metallic iron, 55·52 per cent.
Protoxide of iron	25·44	
Sesquioxide of manganese	0·25	
Alumina	2·64	
Lime, Magnesia	traces.	
Silica	6·55	
Titanic acid	14·01	
Sulphur, Phosphoric acid	not determined.	
	99·95	

The black sands on the coast of California are not unfrequently auriferous, and are sometimes washed for the gold which they afford.

The most productive of these deposits are on the shores in the neighbourhood of the Klamath River in Siskiyou, in Humboldt and San Francisco counties;[1] these are worked spasmodically and without great success owing to the uncertainty of the work and the irregularity of the results due to the difficulties of working deposits mostly covered at high tide, and continually liable to be shifted by the action of the sea. The gold is associated with platinum and is found in small grains, assays varying from $5 to $30 to the ton having been reported.[2]

In New Zealand a great deal of gold has been obtained from beach deposits, especially on the ocean beaches of the West Coast of the Middle Island. These have been worked both in sluices and by dredging, the latter method being at present pursued in several places. Accurate statistics of results seem not to be obtainable, but it appears from the reports of the Mines Department of New Zealand for 1889–90, that two dredging companies were working beach deposits profitably though only obtaining 2·78 grains and 3·17 grains of gold to the ton respectively.

Another very interesting deposit of this class is one that has been worked intermittently on the coast of Malaka to a small extent. On several occasions it has been noticed that tinstone—probably brought down by some of the rivers to the north of this colony—had become concentrated by natural means upon portions of the beach. Occasional rushes of Chinese and Malays to work this beach tinstone have taken place, but the quantity was always small and soon exhausted, and the industry has never remained permanent for any length of time. The last of these rushes was at the end of 1891 and commencement of 1892, when about a couple of hundred men worked the beach for some 20 miles from Kampong Ling to Tanjong Bruas. The ore was found in layers 1 inch to 1 foot deep sloping towards the sea, each patch of ore being, however, of somewhat limited extent. The sand was washed on the spot in little wooden troughs about 7 feet long by means of sea water poured on by hand, and was thus concentrated to about one-fifth or one-sixth of its weight. This was then taken inland to rather larger washing troughs established on the banks

[1] *Reports of the State Mineralogist for California for* 1890 *and* 1892.

[2] A. J. Bowie, *Hydraulic Mining*, 1885, p. 80.

of a convenient stream, and still further concentrated to about two-thirds of its weight, in which state it was offered for sale to the smelters. It proved, however, to be almost all ilmenite with only some 15 per cent. of metallic tin; the difficulty of economically separating these two minerals with the crude appliances mentioned above was too great for the natives or the Chinese, and these workings were accordingly abandoned.

In the Nonkreem valley, Khasia Mountains, Bengal,[1] magnetic iron ore is said to be worked by the natives in the form of iron sands disseminated through coarse reddish sands resulting from the decomposition of soft granite occurring in the locality. The sands are first washed by running a stream of water over them and finally concentrated in troughs. This deposit would seem to be the product of the decomposition *in situ* of granite containing disseminated magnetite.

An occurrence that ought probably to be included in this class is that of gold in laterite. In one or two spots in the north-east of the Malay Peninsula in the Siamese-protected native state of Legeh, a bed of laterite some 6 to 8 feet thick has been sluiced for gold by the Chinese; it is exceedingly poor, apparently containing only a few grains of gold per cubic yard. Laterite is generally supposed to be an indurated volcanic mud, but it might also perhaps in this region be the result of decomposition *in situ* of clay slates under the circumstances of high temperature and excessive rainfall, which obtain in this tropical country. The clay slates are not auriferous where fresh, though they are traversed in places by thin veins of gold quartz. The laterite carries the gold in minute flattened scales, and the occurrence is worth putting on record as a rather abnormal one.

Streamworks.—The detrital tin ore of Cornwall may be grouped under the following heads:—

a. Tin ore forming a constituent of river gravels and sea-beaches actually in progress of formation. The tin ore of such formations usually occurs in angular or sub-angular particles.

b. That found in ancient stanniferous valley-gravels. These occur at all elevations up to about 700 feet, but are invariably in the immediate neighbourhood of considerably higher ground. Deposits belonging to this class were formerly very extensively worked, and have, in the aggregate, yielded large quantities of tin ore.

c. Pebbles and grains found in the "head" or angular *débris*

[1] Dr. Hooker quoted by Dr. J. Percy, *Iron and Steel*, p. 262.

constituting the overburden of the china-clay districts. This differs from the older quartz gravels of some parts of western Cornwall in being both coarser and more angular. Tin ore is also found disseminated through the soil in the vicinity of tin veins.

d. The pebbles and grains of tin ore found in the most ancient high-lying quartz gravels, such as those of St. Agnes Beacon.

Tin streaming, although upon a very restricted scale, was till lately carried on in Cornwall on some inconsiderable stanniferous deposits; but the deeper and more extensive valley-gravels, which were formerly so productive, may be regarded as having long been practically exhausted.

The sections laid open by the deeper streamworks were by no means of uniform interest, but those exposed in Par Valley, at Pentewan, and near the estuary of the Fal, may be regarded as among the most important and instructive.

The Happy Union Streamwork, which has now been closed for more than fifty years, was situated near the *débouchement* of the St. Austell valley at the port of Pentewan. Through this valley flows a stream of moderate dimensions resulting from the union of various rivulets which take their rise on the southern slope of the granitic hills of Hensbarrow. These unite their waters a short distance above the town of St. Austell, and two miles further down the valley receive, through a westerly depression, those collected on the high grounds in the vicinity of the ancient tin mine of Polgooth.

The fall of this valley, in the four miles which intervene between the bridge at St. Austell and the port of Pentewan, is 115 feet, while its width varies from 100 to 200 yards.

The junction of granite with clay slate takes place a short distance above St. Austell, and consequently the bed-rock of the valley, throughout the last four miles of its course, consists entirely of slate.

According to Mr. J. W. Colenso, the Happy Union Streamwork, which may be taken as a typical example of deposits of this class, exhibited the following section:[1]—

1. River sand, silt, &c., 20 feet.
2. Sea sand, 20 feet.
3. Silt, 2 feet.
4. Sea sand, 4 inches.
5. Silt, 10 feet.

[1] *Trans. Roy. Geol. Soc. Cornwall*, iv. 1832, p. 29.

6. Leaves, nuts, acorns,[1] &c., graduating into 6 to 12 inches of silt, and 12 inches of decomposed vegetable matter.
7. Tin ground, 3 to 10 feet.
8. Bed-rock of clay slate.

These various deposits were made up of the following constituents:—

1.—A bed of rough river sand and gravel mixed with sea sand and silt. At the bottom of this, and extending into the bed immediately beneath it, was found a row of wooden piles six feet in length, sharpened at one end for the convenience of driving. These, which had apparently formed part of a foot-bridge, crossed the valley nearly at right angles; their tops being about level with the present low-water mark at spring tides.

2.—A stratum of sea sand, also about 20 feet in thickness, resting upon silt. Throughout this sand were scattered large timber trees, principally oak, strewn in all directions, together with bones of the Irish elk, *Megaceros hibernicus*, and of an ox, *Bos primigenius*, both belonging to extinct species. The bones of a large whale and two human crania were likewise discovered in this sand.

3.—Beneath the sea sand were 2 feet of silt enclosing a few stones, and, occasionally, bones with fragments of wood.

4.—A stratum of sea sand only, 4 inches in thickness, distinguishable from river sand by being finer and by containing fragments of marine shells.

5.—Beneath this was a layer of silt or "sludge," 10 feet in thickness, varying but little in texture, although its colour was in some places darker than in others. In this were numerous marine shells, particularly those of *Cardium edule*, together with bones and horns of the deer and ox. The bivalve shells frequently occurred in regular layers, and when found were closed with their articulations downwards, thus justifying the opinion that the animals had lived and died where their shells were discovered. In this silt was a piece of wood evidently fashioned by human agency, which had probably floated in the sea, since the shell of a barnacle was attached to one end.

6.—A layer of leaves, hazel nuts, acorns, sticks and moss, varying from 6 to 12 inches in thickness. The moss, which was in a very perfect state of preservation, extended across the valley, and had the appearance of having grown where it was found, at

[1] Although Mr. Colenso does not mention acorns in his memoir, they were often found in this layer.

a depth of about fifty feet below the present level of the sea at high water. Beneath this was a stratum of dark silt 12 inches thick, much mixed with decomposed vegetable matter.

7.—To this followed the tin ground, or stratum in which the whole of the tin ore was found. This lay on a solid rock, varied in thickness from 3 to 10 feet, and usually extended completely across the valley. The stony constituents of this stratum were rounded fragments of the granitic and schorlaceous rocks forming the hills north of St. Austell, but fragments of both "greenstone" and clay slate were occasionally met with.

By far the larger portion of the tin ore lay at the bottom of this stratum; but it was also sometimes found in the higher portions of the bed, where, for a thickness of a few inches, the ground was blackened by the presence of tin oxide. The fragments of ore varied in size from the finest sand to pebbles of ten pounds in weight, while boulders, richly impregnated with cassiterite and weighing above two hundred pounds, were not of unfrequent occurrence. A few grains and small nuggets of gold were picked up from among the tin ore, but the remains of no vertebrate animals were ever observed in this horizon. Stumps and roots of trees which had evidently grown and fallen upon the same spot were, however, not uncommon, while immediately on the top of the tin ground an oyster bed was discovered with the shells still firmly attached to the larger stones and to stumps of trees.

8.—The floor or bed-rock upon which these deposits rested is a blue "killas" or clay slate of the kind composing the adjoining hills and neighbouring sea-cliffs. In many places this rock showed indications of erosion, while in others no evidence of any kind of abrasion could be detected.

The bottom of the tin ground at Pentewan was about sixty feet below the present level of high water, and there can be no doubt that the stanniferous gravels were deposited prior to the growth of the woody stratum above them. Similar phenomena have been observed in the Par Valley, at Carnon, in the Fal estuary, and in various other localities. This indicates a general subsidence of the land, and the existence at a former period of a more extended coast-line. On the other hand a connection has been traced by Mr. Carne between a forest bed covering tin ground in the Marazion Marsh, and the submerged forest in Mount's Bay; which further points to a general correlation between the forest beds over the tin ground, and the well-known submerged forests around the south-western coast of Cornwall.

At Huel Virgin, a mile higher up the valley than the Happy Union Streamwork, the overburden contained no sea sand, but was composed of silt and gravel only; the tin ground being found at a depth of thirty-two feet below the surface. Here, resting on the tin-ground, were found two pieces of oak artificially pierced with holes, as were also several oak stakes sharpened and driven into the ground. This streamwork was worked in the usual way by an open terraced cutting, while the water flowed through a culvert to suitable pumping machinery.

It is a remarkable fact, that whenever this excavation was allowed to remain open sufficiently long, certain plants invariably made their appearance along given horizons, to the almost total exclusion of all other species. In this way the first warm weather after the ground was opened, brought with it from a band of bluish silt about 10 feet from the surface, an abundant crop of foxglove, *Digitalis purpurea;* while in a band of clay about 15 feet above the tin ground, a dark rough-leaved willow, not common elsewhere in the district, grew most abundantly.

The cassiterite of Cornish streamworks is in the form of more or less rounded massive fragments, as water-worn crystals, and as wood-tin. With but few exceptions all the larger fragments bear evidence of attrition, and there can be no doubt that, as a whole, the tin ore has been brought together by the mechanical action of water.

There are, however, in the British Museum, as well as in the Museum of the Royal Geological Society of Cornwall, fragments of antlers containing tin oxide, which appears to be pseudomorphous after the organic tissues. Many of these fragments are stated to have been found in the streamworks of the Pentewan and Carnon valleys. Some of the specimens preserved in the British Museum appear to contain a large quantity of tin, as in many parts the original structure seems to be almost entirely reproduced as cassiterite.

A specimen from the Penzance Museum, analysed by Mr. J. H. Collins, gave the following results:—

Calcium phosphate	80·04
,, carbonate	2·24
,, fluoride	·50
Iron disulphide	1·66
Ferric oxide	·62
Stannic oxide	2·60
Silica	·22
Organic matter and loss	12·12
	100·00

A microscopical examination of this antler showed that the oxides of tin and iron, as well as the pyrites, had penetrated to the interior of the mass, and were visible throughout its structure, although they are somewhat more abundant on the outside than towards the middle.[1]

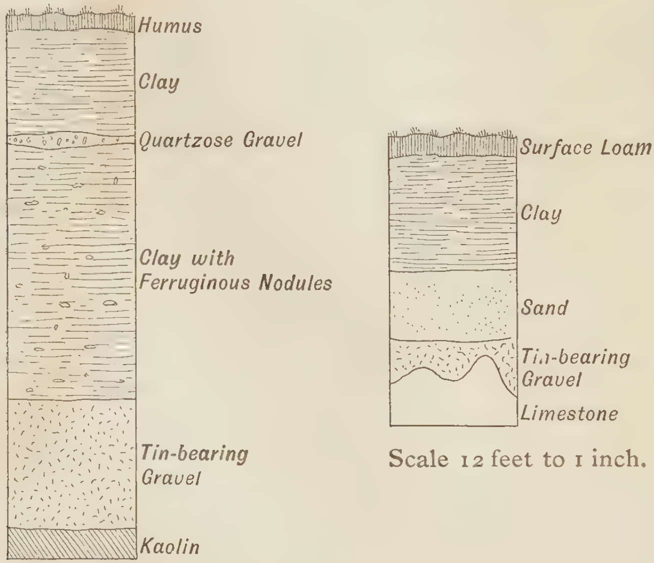
It may be remarked that what is now called stream-working in Cornwall, does not refer to the working of alluvial tin as here described, but to the working of the stanniferous tailings that are allowed to run to waste from the stamp mills that are crushing the tin-bearing veins, the amount of tin thus annually wasted by the mills and recovered by the streamers being very considerable; its value amounted in 1894 to about £29,075, being just about 6 per cent. of that of all the tin raised in Cornwall. The streamworks proper of Cornwall have long been exhausted, as also have those of Saxony; stream tin is however being actively mined in Australia and more especially in Malaysia (the Malay Peninsula and Archipelago), while Burmah, Siam, and China, are known to produce large quantities of stream tin. In Australia, stream tin is produced chiefly in the Colonies of Victoria, Queensland, New South Wales and in Tasmania. Over one-third of the tin-production of these Colonies is due to alluvial tin, which is worked not only in superficial deposits, but in some places in deep beds overlaid by basalt.

The alluvial tin fields of Malaysia are of enormous importance as tin producers, yielding now about three-fourths of the world's entire output. They seem to extend from Burmah and Siam in about 11° N. lat. to Banca and Billiton in about 4° S. lat., the whole of this immense stretch presenting very similar geological phenomena. The tin-bearing gravels are in every case deposited in the beds of the very numerous valleys by which all this region is intersected, the bed-rock being generally a soft white kaolin (the result of the decomposition of granite *in situ*), limestone, or more rarely shales and sandstone. The exact origin of the tin stone has not yet been positively determined,[2] it being ascribed by different writers to disseminated tin stone at the junction of the granite and the clay slates, to veins of tin stone and to ore disseminated in their accompanying country rock, and to the existence of certain tin-bearing granitic zones together with minute veinlets of tin-bearing quartz disseminated through these zones, strictly comparable with the tin stock-works of Saxony and

[1] *Mineralogical Magazine*, iv. 1882, p. 115.

[2] H. Louis, "Straits Tin," *Western Daily Mercury*, February 28, 1895.

Bohemia. This last view has received considerable support from the recent discovery in some deep workings at Kuchai in Selangor[1] of narrow veins of tin oxide traversing a formation consisting of quartz with a little felspar, capped with kaolin, produced by its decomposition *in situ*, and containing much disseminated tin oxide. It is possible that the stanniferous portion of the granite formed a shell on the unaltered central portion, the tin being developed at the junction of the granite with the stratified rocks



Scale 12 feet to 1 inch.

Section at Salak, Perak. *Section at Sungei Sempah, Selangor.*

Fig. 8.—Sections of Malayan tin-gravels.

on its flanks, as is the case also in the Erzgebirge; see p. 172. The sections in Fig. 8 show the general character of the deposits in the Malay Peninsula. The stanniferous gravel varies in thickness from 1 foot to 15 feet, usually more or less in proportion to the depth of the overburden, which varies between 5 and 80 feet. An exceptional occurrence is that at Sorakai, Kinta, in Perak, where the tin gravel was reached after sinking through 20 feet of overburden, and was then worked for a thickness of 80 feet, when the water became so heavy that the Chinese miners

[1] *Reports on the Protected Malay States for* 1894, p. 35.

had to abandon further work without reaching bed rock. The proportion of overburden to tin gravel in the Malay Peninsula seems to average about 4 to 1, and 6 to 1 is probably about the limit below which the Chinese do not care to work. According to C. M. Rolker[1] the proportion in Sumatra is about 10 to 1, practically the same as it is in Banca. In the Malay Peninsula the richness of the tin gravels is from 5 lbs. to nearly 40 lbs. per cubic yard. The former figure was obtained from some very careful measurements by the writer[2] in ground considered very poor by the Chinese, the latter is an average estimate from several authorities. According to Rolker the yield in Sumatra was 0·12 per cent. or say about 3·6 lbs. per cubic yard, whilst in Banca it seems to be from 40 to 60 lbs. of black tin according to Van Diest (quoted by Rolker, *loc. cit.*). Of course very much richer patches are sometimes met with, especially when the bed rock is limestone, and when the tin sands have been concentrated and have accumulated in pot-holes; in these cases the sands have been known to yield as high as 20 per cent. of black tin. The tinstone seems in every case to be very pure, assaying generally from 70 to 75 per cent. of metallic tin; it is often pale brown or even white, but generally black. It is found in pieces of all sizes varying from fine sand to boulders weighing exceptionally 10 cwt. The accompanying minerals in the stanniferous gravels are mostly magnetite and ilmenite, derived no doubt from the granites whose weathering liberated the oxide of tin, and thus formed these clastic deposits.

GROUP *b*. PRECIPITATIONS FROM AQUEOUS SOLUTIONS.—These would seem to be found in formations of all ages from the oldest to the most recent, some such deposits being still in process of formation. It appears however that most of the older deposits are older than Mesozoic times, whilst the modern ones are mostly quite superficial. It may therefore be convenient to consider them apart, the processes that we see going on before our eyes giving us valuable clues as to how the older beds may have been deposited. It is not however always easy to distinguish a deposit thus directly precipitated from one that has been formed by metasomatism or segregation, the characteristic of permanence over a large area that marks the class now being considered being of great importance in this connection. Deposits of this group are practically confined to ores of iron and manganese.

1 "The Alluvial Tin Deposits of Siak, Sumatra," *Trans. Amer. Inst. Min. Eng.*, xx. 1891.

2 H. Louis, "Straits Tin," *loc. cit.*

Recent Deposits.—The most important surface deposits belonging to this class are those of bog and lake iron ores. These, which often contain oxide of manganese, although generally somewhat impure, are essentially hydrated peroxide of iron ($H_6Fe_2O_6$), containing when pure 14·42 per cent. of water. Phosphoric acid is, however, frequently present in sufficient quantity to affect their value as a source of iron.

This mineral is sometimes hard and compact; while at others it is friable and granular, occasionally enclosing the petrified forms of vegetable organisms. Concretionary nodules, as well as oolitic and pisolitic forms of this ore, are of frequent occurrence. In all cases it is the result of the alteration of other mineral substances containing iron when acted upon by air, moisture, or acids, and is, to a large extent, due to the oxidation of pyrites, and to the action of carbonic acid upon siderite, &c. The decomposition of ferriferous rocks and various ferriferous minerals, such as mica, augite and hornblende, also contributes largely to the formation of ores of this class. All these sources are capable of yielding up iron to surface waters. Organic acids such as are produced by the decomposition of vegetable matter are powerful solvents of iron.

Attention was first called by Kindler to the importance of the effects produced by decaying vegetable matter on the solubility of ferric hydrates.[1] He observed that where pine trees had been planted upon sand-hills in such a position that falls of sand were occasioned by the action of running water, the ferruginous and quartzose sand was rendered colourless around decaying roots, and that it became in the course of a few months as white as if it had been treated by an acid. The action of a root one-sixth of an inch in diameter whitens the sand to a distance of from one to two inches around it.

Carbonic acid dissolved in meteoric waters will readily dissolve iron as a bicarbonate when it exists as a carbonate, either pure or as an ingredient in ferriferous dolomites and limestones. In the presence of organic matter limonite can be reduced to the state of protoxide, carbonate of iron being thus produced and dissolved. The oxidation of pyrites produces soluble sulphates, both ferrous and ferric. All of the above chemical reactions are probably operative in producing actual solutions of iron in surface waters, whilst the frequent occurrence of chalybeate springs proves that similar reactions take place in deeper seated regions of the earth's crust. When such waters are exposed in flat sheets, such as ponds,

[1] *Poggendorff's Annalen der Physik und Chemie*, xxxvii. 1836, p. 203.

to the action of the air, carbonic acid is evolved and the iron is deposited, either as carbonate when the reducing action of decaying vegetation protects the iron from the oxidising influence of the atmosphere, or as hydrated peroxide when this latter action is operative. All the above reactions having been imitated in the laboratory, their occurrence under laboratory conditions may be taken as established, and it is more than probable that they also take place in nature.

Although not at present much worked in Great Britain, these ores probably supplied to some extent the earlier forges established in the Weald of Kent and Sussex, which, during several centuries, furnished a very considerable proportion of the iron manufactured in England. The ore chiefly employed was, however, a clay iron stone obtained in the immediate neighbourhood. Bog and lake iron ores occur plentifully in various parts of Europe, particularly in North Germany, Sweden, Norway, and Finland, and are largely employed in the manufacture of iron. Bog iron ore is abundant in the United States and Canada, and in the latter country it is somewhat extensively employed.

One of the principal occurrences in Canada is in the Three Rivers District, Province of Quebec,[1] where bog iron ore seems to have been smelted as early as 1730 or thereabouts. The northern limit of the extensive area within which these ores occur, is the Laurentide range of mountains, which appear to be rich in iron ores in Archæan rock formations. Beds of hard bog ore are found on the hillsides above the numerous swamps and marshes of this district, whilst in the swamps the ore appears to be in a softer state, though it rapidly hardens when its water is drained from it and it is exposed to the air. In the swamps the ore is found as a rule 12 to 18 inches below the surface, but good ore has been got as deep down as 8 feet, and there are strong indications of good ore beds in excavations 15 feet deep. In the valley of the St. Lawrence in the region about Three Rivers, the surface consists nearly everywhere of sand underlain by a stiff blue clay, which clay has in many places formed extensive swamps. These support a dense vegetation, by the decay of which as already explained iron is dissolved out from the Archæan rocks which contain disseminated magnetite and ilmenite. The solutions of iron thus formed percolate through the adjacent sands where they come into contact with atmospheric oxygen in the porous soil, the iron being precipitated in concretions about the particles of sand;

[1] *Trans. Amer. Inst. Min. Eng.*, xxi. 1892, p. 974.

patches of ore from 3 to 30 inches thick and from a few square feet to several acres in extent are thus formed. A small lake, Lac à la Tortue, about 3 miles long by 1 broad in this district, has yielded large quantities of ore, formed in a similar manner. It is fed by a number of small streams flowing in from the surrounding swamp, all of which are highly charged with iron, so much so that the lake has a chalybeate taste. This solution becomes oxidised at the surface of the lake and concretions of ore gradually form and sink to the lake bottom, where they are found as flat porous masses, the largest being some 8 inches in diameter. It is noteworthy that the ore forms with considerable rapidity, it having been found that paying quantities can be obtained from areas completely exhausted some eight or ten years ago.

The following analyses show the average composition of I. the bog-ore and II. the lake-ore :—

	I.	II.
Ferric oxide	60·74	70·04
Manganic oxide	1·18	1·78
Alumina	2·59	2·20
Lime	3·47	0·32
Magnesia	0·93	0·27
Phosphoric anhydride	0·69	0·76
Sulphuric anhydride	0·19	0·23
Silica	13·94	7·84
Loss on ignition	16·49	16·84
	100·22	100·82
Metallic iron	42·52	49·03
Phosphorus	0·302	0·331
Sulphur	0·078	0·093

At Meadow Vale, Nova Scotia, large nodular masses of bog iron ore occur about a foot below the surface of the ground in swampy land ; the iron has evidently been derived from the extensive neighbouring deposits of iron ore ; on account of the presence of this higher grade ore in considerable quantities, the impure bog-ore has not been worked, although it carries about 47 per cent. of metallic iron. A similar occurrence in layers 6 inches to 2 feet thick is known at Bloomfield, this ore yielding 25 per cent. of metal. Other similar deposits occur in Pictou County and at Fox Brook, Cape Breton.[1] Bog-ore is thus widely distributed in this province, but it is important to note that every one of these occurrences is to be found in the immediate neighbourhood of important deposits of iron ore in the older rocks.

Large quantities of lake iron ores are annually obtained in

[1] Edwin Gilpin, *Report on the Mines and Mineral Lands of Nova Scotia*, 1880.

Finland and Sweden by dredging from the bottoms of the lakes so numerous in those countries. The ores may occur either on the spot in which they have been precipitated, or they may, on the contrary, be carried by the force of running water into lakes or ponds at some distance. They are, however, usually found in the neighbourhood of rush-banks, and on the slopes and shallows of some of the larger and deeper lakes, in patches varying greatly in extent and thickness. The work of collecting these ores is limited to the winter months, when, the lakes being frozen over, they are obtained by breaking holes in the ice and scooping them up by means of perforated shovels. Ores of this class are being continually reproduced, and lakes in which they had become completely exhausted by dredging, have, after the lapse of a quarter of a century, been again found to contain beds several inches in thickness, which must necessarily have been deposited during that period.

The occurrences of bog-ore and lake-ore in Sweden and Finland are almost identical with those at Three Rivers. The lake-ore is the more important form; in Sweden it is found chiefly in the province of Småland, and receives various names according to the size of the concretions of which it consists,[1] the following being its average composition:

P_2O_5	from	0·253	to	1·128
SO_3	,,	trace	,,	0·127
CaO	,,	0·615	,,	2·683
MgO	,,	0·021	,,	0·731
Al_2O_3	,,	2·167	,,	7·894
SiO_2	,,	5·854	,,	41·258
Fe_2O_3	,,	45·260	,,	69·953
Mn_2O_3	,,	0·463	,,	16·185
Water, organic matter, and loss	,,	7·576	,,	16·219

The ores of Finland are very similar in character and composition.

It was first suggested by Ehrenberg (1836) that these ores are produced by certain infusoria, which build cells mainly composed of hydrated oxide of iron The Gaillonella ferruginea is said especially to be an industrious manufacturer of iron ore by secretion from dilute iron solutions.

A deposit of bog iron ore now in process of formation, and which most admirably exhibits the genesis of this class of deposit occurs in Park County, Colorado. It has been described as follows by Professor Regis Chauvenet:[2] "The South Platte river has a

[1] J. Percy, *Iron and Steel*, p. 324.

[2] *Trans. Amer. Inst. Min. Eng.*, xviii. 1889, p. 268.

number of forks, and it is on the north fork, or the streamlets which unite to form it, that the beds in question are now forming. In two little valleys, known as Hall's Valley and Handcart Gulch, we find an abundant supply of bog-ore, its character being 'mixed,' however, in the present stage of formation. The bed in Handcart is the more typical of the two. We find, as we ascend the gulch, that the stream is so strongly ferruginous, from the ferrous sulphate dissolved in it, that its inky taste is quite disagreeable. As we trace it to its head-waters, which are close to the main divide of the continent, we see the rocks above blazing in red and yellow from the oxidation of the chalybeate water, which percolates through them charged with the sulphate, the result of the solution of pyrites, great beds of which are known to exist in the region. Descending into the lower part of its narrow valley, the stream runs into what is almost a marsh, with dense vegetation, and here it deposits iron so completely, forming the still growing beds of limonite, that iron can with difficulty be distinguished by the chemist in the issuing water. Every stage of the ore-formation can be traced, or, one might say, seen. Tufts of bog vegetation can be pulled up from a mush of half-formed oxide, the roots crusted with incipient ore, while from the more solid portions, nearer the present bed of the creek, true ore can be found in considerable quantities. Some of this has been analysed by the writer with the following result:

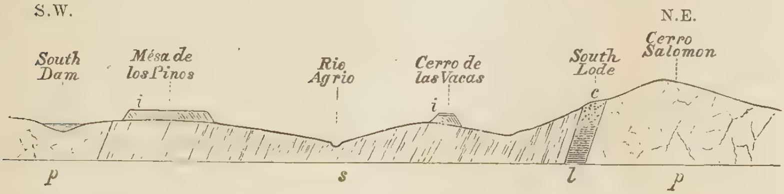
SiO_2	7·13
Fe_2O_3	67·55
P_2O_5	1·82
CaO	1·22
H_2O and organic matter	22·37
Total	100·09

Here, then, is a bed of ore in actual process of construction. It would be possible to-day to extract from it much ore fit for smelting, and it can hardly be doubted that in a future age it will present all the features of a true solid limonite deposit."

A remarkable bed of compact and exceptionally pure iron ore of this class forms the capping of a hill at Rio Tinto in the province of Huelva, Spain, in close proximity to the celebrated copper mines of that name. In Southern Spain deposits of cupriferous iron pyrites, having a general direction somewhat north of west and south of east, extend from near Seville to within the Portuguese frontier. At Rio Tinto the deposits of this mineral are very extensive, and consist of a compact and intimate admixture of iron pyrites with a little copper pyrites, through which strings of the latter mineral sometimes ramify.

Although these mines have been worked, and the copper smelted, from time immemorial, it is evident from coins which have been discovered, that their great development under the Romans took place during the first four centuries of the Christian era. The prevailing rocks throughout the region are clay slates, which, from the evidence of various fossils, are apparently of Silurian, Devonian, and Carboniferous age. These slates are broken through by dykes of quartz-porphyry, which frequently form one of the walls of the deposits of cupriferous pyrites.

Fossiliferous iron ore forms a cap three-fifths of a mile long, with an average width of 140 yards, on the top of the Mésa de los Pinos, 984 yards south of the great open cutting at Rio Tinto. Its surface is approximately level, but its depth varies from one



p Porphyry. Slate. *i* Iron caps. *l* Lode. *c* Capping of lode

FIG. 9.—Transverse Section; Rio Tinto.

to seventeen yards in accordance with the conformation of the surface of the rock upon which it lies. The slate beneath it is bleached and to some extent decomposed.

The relative positions of the several formations will be understood on referring to Fig. 9.

On the extreme right is a broad hard porphyritic dyke forming the north wall of the south lode, next to which is the great mass of pyrites, which at this point has only one-third of its greatest width. Next in succession, to the south, comes a band of slate which is again penetrated, on the left, by a broad dyke of quartz-porphyry, now much decomposed. The upper part of the pyrites deposit has, to a considerable depth, been converted into a ferruginous capping, of which a large portion has been removed by denudation. The stratum of iron ore forming the surface of the Mésa de los Pinos has precipitous sides; and a small outlying patch of a similar formation occurs, within a metre of the same elevation, at the Cerro de las Vacas. Numerous fissures occur in the surface of the larger deposit of iron ore, and, out of these, pine trees formerly grew, their presence giving the name to the locality.

An exceptionally pure specimen of this iron ore afforded on analysis the following results:—

Water	13·25
Silica	1·53
Ferric oxide	84·65
Alumina	trace
Phosphoric anhydride	·14
Sulphur	·23
	99·80

During the process of quarrying this ore, the presence was observed of the fossil remains of the leaves and seeds of plants belonging to species still growing in the neighbourhood, as well as of several well-preserved beetles.

Any doubt as regards the recent character of these fossils has been removed by Mr. W. Carruthers, who found the specimens from Rio Tinto to contain fragments of the following plants, which he was enabled to identify:—Leaves and acorns of *Quercus ilex,* Linn.; leaves and seeds of a two-leaved species of *Pinus*, most probably *Pinus pinea*, Linn.; the cone of *Equisetum arvense*, Linn.; and a small branch of a species of *Erica.* The greater portion of some specimens of the ore represented a thick growth of moss, but it was impossible to say of what species. The whole was permeated by minute branching roots, showing that the vegetation was formed as a peat-moss, the oak and pine leaves having been carried or blown into it. The plants evidently belong, all of them, to species still found growing in Spain. In addition to these fossils, this deposit occasionally contains minute concretionary patches of imperfectly crystallised quartz.

The origin of this deposit of iron ore can scarcely be doubtful. At the time of its formation a marsh or shallow lake extended from beyond the Mésa de los Pinos to the foot of Cerro Salomon, and into this flowed solutions of iron salts resulting from the decomposition of the upper portions of the immense mass of pyrites constituting the south lode. From these salts oxide of iron was deposited, as in the case of bog iron ores generally; and finally the valley of the Rio Agrio was eroded, as well as that south-west of the deposit, leaving the Mésa capped with iron ore, while a small patch of the same mineral was left at the Cerro de las Vacas. The mode of formation of this deposit is thus quite similar to that described in Park County, Colorado.

That this deposit took place at a comparatively recent date is evident from the fossils it contains, and it is equally certain that the erosion of the valley is older than the occupation of the district by the Romans. Not only are remains of buildings and other works belonging to the Roman period found in the valley, but the Roman gravestones, of which many are still scattered over the district, are invariably made of this iron ore.

Deep-lying Deposits.—These have no doubt in many, if not in all, cases been formed by processes similar to those that produced the surface deposits, whose mode of origin we are in many cases able to trace, but owing to their greater geological age, the former have been more or less altered, and have undergone the various upheavals, foldings, and faultings which have affected the rocks between which they lie.

They are mostly ores of iron and manganese, and although found in formations of all ages, their maximum development is in the older rocks. The Carboniferous rocks of both England and America are especially rich in interstratified beds of argillaceous ironstone. Argillaceous carbonate of iron was for a long time one of the most important sources of iron in the United Kingdom, and furnished a large proportion of the iron annually produced.

Argillaceous carbonate of iron is found either interspersed through the clays and shales of the coal-measures, or, less frequently, among the argillaceous members of Secondary or Tertiary strata. The nodular variety, which is the most abundant, essentially consists of carbonate of iron associated with carbonates of lime, magnesia, and manganese ; it also invariably contains a considerable proportion of clay. In some instances the nodules of ironstone coalesce into beds, but these are usually restricted both in extent and in thickness. Nodular ironstone is for the most part concretionary in structure, being formed of concentric deposits, which frequently enclose fossil fish, shells, or plants. Ferruginous septaria are often traversed by fissures similar to those produced by the shrinking of clay in drying, and these are filled, as in veins, with such minerals as calcite and quartz with, occasionally, pyrites, blende, galena, millerite, or hatchettine, the two last being associated together in the clay ironstone of Dowlais in Glamorganshire.

Sphærosiderite, when freshly broken, ordinarily presents a yellowish or bluish-gray fracture, which, owing to a superficial peroxidation of some of the iron, becomes brown on exposure. Clay ironstones contain from about 29 to 37 per cent. of iron, and phosphoric acid is usually present in varying amounts.

Blackband is a clay ironstone containing a considerable amount of carbonaceous matter, and is exceedingly valuable from the cheapness with which it can be calcined without the addition of fuel. The calcined residue from this ore contains from 50 to nearly 70 per cent. of iron. In the coal-fields of Western Scotland several blackband measures are known, having an aggregate thickness of nearly six feet. In Staffordshire it occurs in beds of from four to nine feet in thickness, and it is also found in numerous small irregular beds in North Wales. The Rhenish and Westphalian coal-fields likewise yield this ore.

The most productive iron-bearing members of the Secondary rocks are the Lias, Great Oolite, Wealden, and Lower Greensand, yielding brown hæmatite and earthy carbonate, which although in the majority of cases of low quality, are rendered of great commercial importance by the extremely cheap rate at which they can be mined.

The Middle Lias is the most productive formation of iron ores in England, its greatest development being in the Cleveland district; the main seam, which is the one chiefly worked, extends over an area of some 350 square miles, although it does not seem probable that it can be worked profitably for over a fifth of that area.[1] There are several bands of the ore, varying in thickness and relative position, two beds in places running together, and forming but one, although the general strike and dip of the seams are fairly uniform. Its average iron contents, when uncalcined, may be taken at about 30 per cent. with 1·5 per cent. of phosphoric acid.

In France and Southern Germany large quantities of *bean ore*, a coarse-grained pisolitic iron ore, is procured from irregular deposits in rocks of Oolitic age. A series of beds of impure brown hæmatite, known locally as *Minette*, extend over an enormous area of central Western Europe, and form the principal source of iron supply for France, Germany, and Luxembourg. The number of beds and their thickness varies in different districts, but their geological relations are everywhere the same, their horizon being the base of the Lower Oolite. These ores contain an average of 33 per cent. of metallic iron and 0·8 per cent. of phosphoric acid. The amount of iron in ores of Secondary age usually varies from

[1] J. D. Kendall, *The Iron Ores of Great Britain*, 1893, p. 213.

about 32 to 48 per cent. while the proportion of phosphoric acid is sometimes as high as 2 per cent. or even more.

There is but little iron ore of Tertiary age in this country, the principal deposit being at Hengistbury Head in Dorsetshire. Tertiary iron ores, however, occur on the Continent, and are somewhat extensively collected from surface deposits in France, Germany, and elsewhere; many of these deposits are of a detrital character.

The separation of mineral matter from masses of rock through which it was originally but sparsely disseminated is well exemplified in the ironstone nodules of the Coal-measures, which evidently result from the separation and aggregation of carbonate of iron from the surrounding shales and clays.

The calcareous nodules of the Lias and the argillaceous deposits known as septària, and similar nodules in the Old Red Sandstone of Scotland and South Wales, sometimes termed "cornstones," have, in the same way, resulted from the separation of a small amount of calcareous matter, originally distributed through the mass of argillaceous and siliceous sediments. Not unfrequently these argillo-calcareous nodules contain fragments of the enclosing stratified rock, layers of which may be traced through them; the laminæ having the same direction as the mass of the rock of which they originally formed part. This has been observed in nodules from the Lias of Lyme Regis, and in the calcareous septaria, containing fossilfish, in the Old Red Sandstone of Cromarty, &c. In the same way siliceous particles originally disseminated in calcareous rocks such as Chalk, Portland Limestone, Coral Rag, and Carboniferous Limestone, have separated out and become segregated into the various forms of flint, chert, or hornstone now occurring in those rocks, and sometimes enclosing portions of the original beds, or a nucleus of some fossilised organism. Occasionally the siliceous matter has filled the more or less vertical fissures of calcareous rock, or even replaced its original substance;[1] such veins of flint are well seen in the chalk cliffs of Ramsgate, and in the Portland beds of Tisbury, Wiltshire. In a similar manner the nodules of phosphate of lime which occur in certain fossiliferous strata have evidently been derived from the aggregation of their components, previously distributed in the mass of the original deposits. It is well known that the plastic clay prepared for the manufacture of pottery and porcelain is mixed with finely ground silica, and from such mixtures, if not

[1] T. Rupert Jones, *Reliquiæ Aquitanicæ*, 1875, p. 202.

used in proper time, it is stated the silica becomes aggregated into hard lumps or nodules, which render them useless for the purpose of porcelain making.

Group *c*. Deposits from Solution, subsequently Metamorphosed.—The previous group consisted of ores either deposited at the surface, or else somewhat consolidated and altered by incipient metamorphism, but nevertheless retaining most of the characteristics that they had when freshly formed. The present group embraces such ores in which the metamorphism has advanced so far that they are no longer recognisable in any shape in which ores are precipitable in a bed by any process of nature known to us, so that we are forced to assume that they were originally deposited like those of the previous group, but have since then undergone complete chemical and structural metamorphism, by the action of subterranean heat and pressure. This group has close affinities with that group of irregular deposits which is connected with igneous rocks, and it is quite possible that bedded deposits, which were originally of but small extent and of great thickness, and have since then undergone very complete metamorphism together with the rocks enclosing them, might be included with those irregular deposits. When, as in this case, purely genetic considerations are at fault, morphological considerations must be given full weight, and not only the dimensions of the ore deposit, but its high or low angle of inclination must be taken into account in classifying it. Iron ores occurring in highly metamorphosed rocks are usually either in the state of ferric oxide, Fe_2O_3, or magnetite, Fe_3O_4. Both these minerals are obtained from beds, lodes, and massive deposits, for the most part enclosed in rocks of Cambrian, Silurian, Devonian, or Carboniferous age. Red hæmatite is sometimes crystalline, sometimes fibrous, columnar, botryoidal, granular, or compact. Among the most important European deposits of hæmatite are those of the Island of Elba, of Dalkarlsberg near Nora, and those of the Island of Utö, in Sweden; in the two latter localities it is associated with magnetite. In the Island of Utö the ore is made up of parallel layers of a very brilliant specular variety of hæmatite with quartz, and is therefore not unlike the rock known in Brazil as *itabirite*.

In the Huronian rocks near Marquette, on the southern shore of Lake Superior, are large deposits of schistose hæmatite, known by the name of *iron slate* or *specular schist*, which have long been extensively worked. The strata enclosing these ores are much contorted, and are chiefly composed of talcose and chloritic schists, gradually passing into parallel bands of jasper and hæmatite. Much of the rock, although highly ferriferous, is still too siliceous to be worked for iron; but beds of solid hæmatite, of great thickness and free from earthy impurities, are quarried at the Republic and Superior Mines in the district. In addition to hæmatite affecting the usual crystalline form, these beds enclose numerous crystals of the octahedral variety of ferric oxide known as *martite*.

Important deposits of the same class have more recently been opened on the north shore of Lake Superior in the Mesabi range; these have been traced as occurring at intervals over a length of 140 miles, the width of the ore belt nowhere exceeding two miles, and being generally less than one mile.[1] The ore occurs in beds up to 100 feet in thickness. These ores are of Taconic age, this formation overlying unconformably the Archæan green schists of the Keewatin, and being overlaid in turn by gabbro. The lowest member of the Taconic series here is a quartzite, upon which rests a series of strata, consisting of siliceous and calcareous rocks banded with layers of oxide of iron, which is either magnetite or hæmatite. Eastward from Birch Lake the gabbro seems to have flowed over the iron belt, and in doing so, it has converted the ore into magnetite, the effect having extended for miles away from the edge of the gabbro flow; whilst towards the Mississippi the ore is practically all hæmatite. Mr. Winchell (*loc. cit.*) seems to hold the opinion that these deposits are due in part to "oceanic precipitation as hydrated sesquioxides at the time of the original sedimentation" of the Taconic rocks with which they are interstratified, "subsequent pressure and heat having dehydrated the ores, and the gabbro outburst rendered them magnetic," and that in part they are due to replacement of the quartzose constituents of the "taconite" rock by oxide of iron at a period subsequent to the gabbro outburst. Should this view be correct (and further studies of the deposit seem to be needed before it can either be rejected or unhesitatingly accepted), then will this deposit, like not a few others need to be placed in two widely different groups upon any purely genetic system of classification. In addition, it is proper to remark that Mr. Wadsworth[2] ascribes to these beds of ore and the associated "Jaspilite" a purely eruptive origin.

Another bed of hæmatite of great importance economically

[1] Horace V. Winchell, "The Mesabi Iron Range," *Trans. Amer. Inst. Min. Eng.*, xxi. 1893, p. 644.

[2] *Report of the State Geologist of Michigan*, 1893, p. 106.

as well as of high geological interest is the great bed of "Clinton" ore, which is found cropping in most of the Eastern and Central States of North America. Wherever the Clinton stage of the Upper Silurian crops out, it almost invariably contains one or more beds of red hæmatite interstratified with the shales and limestones.[1] The ore is sometimes a fairly pure hæmatite, sometimes little more than a highly ferruginous limestone. It occurs massive, concretionary, and at times full of fossils, chiefly mollusca and crinoids. The annexed section at Montour Ridge, Danville, Pennsylvania, after H. H. Stock,[2] will illustrate the geological features of its occurrence.

It seems pretty well proved that this ore was formed by deposition in shallow waters in a manner analogous to the formation of the lake-ore; some of it, however, is probably due to the metaso-

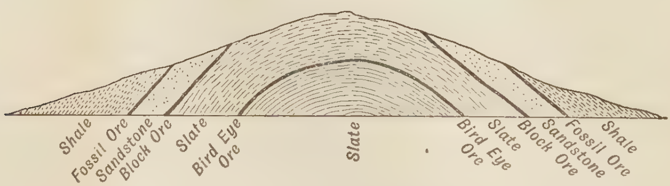


FIG. 10.—Section of iron-ore beds at Montour Ridge, Pennsylvania.

matic change of limestone beds into iron ore, or to the gradual leaching out of the calcareous constituent from a ferruginous limestone bed.

There are a series of beds of supposed similar age at Nictaux in Nova Scotia. In this district, which is still very imperfectly explored, there are a number of beds of magnetite and hæmatite, whilst other beds consist of both minerals mixed; these beds are from four feet to ten feet in thickness and course about E.N.E.—W.S.W., their dip being in places nearly vertical. Some of these beds are of massive ore, usually fissile parallel to the plane of bedding, whilst other beds contain numerous fossil remains, chiefly of *Spirifer Nictavensis*, also species of *Avicula*, *Bellerophon*, &c. Sir William Dawson considers these beds to be of Lower Devonian age, but one of the embedded fossils brought back by myself [H. L.] has been recognised by Professor Lebour as *Posidonomya Becheri*,

[1] J. F. Kemp, *The Ore Deposits of the United States*, 1893, p. 92.

[2] "Notes on the Iron Ores of Danville, Pa.," *Trans. Amer. Inst. Min. Eng.*, xx. 1891, p. 371.

which would fix their age as Lower Carboniferous. The following are analyses by H. Louis:—

I. of magnetite from Cleaveland Mountain, Nictaux; II. of fossil ore, and III. of amorphorus fissile hæmatite from Nictaux.

	I.	II.	III.
Insoluble	18·95	18·13	9·42
Fe_2O_3	48·34	71·81	66·60
FeO	21·76 (calculated)	—	8·83
Al_2O_3	1·62	3·59	8·12
MnO	0·40	0·28	0·49
CaO	4·01	2·50	2·50
MgO	0·60	1·00	0·49
CO_2	not determined	not determined	0·52
Combined water			2·33
P_2O_5	3·08	1·25	0·69
S	0·08	—	trace
	98·84	98·56	99·99
Fe metallic	50·77	50·27	53·49

There can be little doubt but that these beds were deposited like the previous ones, and that they have subsequently undergone metamorphism, although the fossil ore is probably metasomatic. It is noteworthy also that these beds are the source whence the bog iron ore of this district, previously referred to (page 38), was derived.

The celebrated Pilot Knob Mine near St. Louis, Missouri, is worked on ores of a nearly similar character to those of Lake Superior. They form a couple of beds of hard specular hæmatite interstratified with breccias and sheets of porphyry,[1] the lower bed being from twenty-five to forty, and the upper bed from six to ten feet thick; they lie flat, the average dip being 13°. The exact mode of origin of these ores is still very obscure, though most authorities seem to refer them to original sedimentation. At Cornwall, Pennsylvania, there are immense deposits of bedded magnetite, containing a good deal of iron pyrites and some copper, but so low in phosphorus as to make an excellent Bessemer ore. The deposits form three low hills, showing in places a thickness of 300 feet of ore, lying upon sandstones and associated with trap rocks, the hills appearing to be the eroded remains of a large deposit. There are no important continuous beds of hæmatite in the United Kingdom.

Magnetic iron ores, when they occur in a massive form, usually contain a larger proportion of oxygen than is indicated by the formula Fe_3O_4, thus indicating the presence of a certain amount of hæmatite. Magnetite occurs in extensive irregular beds or

[1] J. F. Kemp, *The Ore Deposits of the United States*, 1893, p. 114.

stratified deposits in various European countries, being usually enclosed in crystalline metamorphic rocks and associated with such minerals as hornblende, epidote, garnet, idocrase, chlorite, apatite, quartz, felspar, pyrites, &c.

There can be but little doubt that the majority of these stratified deposits of crystalline iron ores were originally thrown down in a hydrated form from aqueous solutions; but having been subsequently exposed to metamorphic influences, they have not only lost their combined water, but, like the rocks enclosing them, have become crystalline. It is probable that, in some instances, they may have been deposited as carbonate of iron, which first lost its carbonic acid and subsequently became more highly oxidised.

Professor J. S. Newberry, in a valuable contribution to the *School of Mines Quarterly* for November, 1880, enumerates the sources whence the necessary supply of iron may be derived.

In the oldest existing rocks of which we have any knowledge iron is an important constituent of many minerals, such as hornblende, garnet, biotite, &c., and in rocks of this description deposits of iron ore, commonly as magnetite in the granites and as hæmatite in the slates, are of frequent occurrence. Deposits of this class were formerly supposed to be of eruptive origin, but more recently it has been pointed out by various authors that, almost without a doubt, they are of sedimentary origin. The magnetites and hæmatites of the older rocks become by exposure converted into hydrated ferric oxide, which alteration is constantly attended by a change of structure resulting in exfoliation. Iron oxide thus becomes mixed with the soil, where it is exposed to the action of carbonic acid and various other acids, resulting from the decomposition of vegetable matter. By these it is dissolved, and becomes a constituent of the surface drainage of the country, to be carried a greater or less distance, and finally deposited in the form of an ore of iron. In the same way various minerals containing iron, such as hornblende and garnet, forming constituents of the rocks, are gradually dissolved by carbonic acid and other solvents, and thus pass into solution. Iron pyrites undergoes a somewhat different form of decomposition, since both its constituents become oxidised with the formation of sulphate of iron, from which oxide of iron is ultimately deposited.

In continuation of this subject Dr. Newberry then proceeds to say:—"Having now got the insoluble peroxide of iron into a soluble form, let us follow it in its travels. All the drainage of a forest-covered country may be asserted to contain iron. Where the rocks and soils hold this metal in unusual quantities, the amount dissolved and transported is proportionately great, and many of the springs are chalybeate. Wherever these solutions of the salts of iron are exposed to the air they absorb oxygen, and the iron is converted into the hydrated sesquioxide. This we see in the precipitate of iron springs as yellow ochre; in bogs and pools it forms an iridescent film which, when broken, sinks to the bottom of the water. If it there finds decaying organic matter, it is robbed of a portion of its oxygen, which unites with the carbon to form carbonic acid, and this, bubbling to the surface, escapes. The iron thus becoming again a soluble proto-salt, and floating off, absorbs more oxygen, and carries this also to the organic matter, continuing to do this until all is oxidised; then it is precipitated as limonite or bog iron ore. Thus it will be seen that, under such circumstances, iron plays the same part that it does in the circulation of the blood, where it is oxidised in the lungs and carbonised in the capillaries, serving simply as a carrier of oxygen." Beds of iron ore thus formed naturally become metamorphosed at the same time as the enclosing rocks, and give rise to deposits either of magnetite or hæmatite in accordance with varying conditions.

GROUP *d*. DISSEMINATIONS THROUGH SEDIMENTARY BEDS.—This important group may in one sense be looked upon as a kind of connecting link between the two great classes of deposits, the symphytic and the epactic, because, while the bulk of the bed itself, namely, the non-metallic portion, has been deposited like any other rock stratum and is therefore symphytic in the sense in which the word has been here used, the valuable metalliferous portion, the true ore deposit, is of later formation and has been introduced subsequently to the deposition (and probably even to the consolidation and elevation) of the bed. Many writers have argued in favour of the view that these beds are true contemporaneous deposits in the strictest sense, holding that the metallic constituents have been deposited simultaneously with the rock-forming detritus of which the beds consist. Obviously, positive proof or disproof is impossible, but what evidence there is seems to be against this view. It appears to be certain that the water of the ocean contains minute traces of copper and also of silver; the existence in it of gold is said to be more doubtful, nor has that of lead ever been demonstrated.[1] This subject has, however, been quite recently studied

[1] E. C. C. Stanford, Presidential Address, *Journ. Soc. Chem. Ind.*, xiii. No. 7, 1894, p. 697.

by Prof. A. Liversidge, who finds 0·5 to 1 grain of gold to the ton of sea-water off the Australian continent.[1] It is, however, difficult to imagine the conditions under which a bed of sand or shale could be deposited with minute disseminated particles or concretionary nodules of galena or copper sulphide distributed simultaneously throughout it. Again, these deposits are not confined to beds of proved marine origin, but some may very well have been formed in fresh water, in which the existence of these metals has yet to be proved. Many of the metals occurring in these beds appear as sulphides; it is known that subterranean waters carry metallic sulphides in solution, whilst sea-water apparently does not. It is even difficult to imagine these metals existing in sea-water except as chlorides, so that for their precipitation a complicated interaction between these salts, sulphate of lime, and decomposing organic matter would have to be invoked; though not impossible such a reaction seems antecedently improbable. The strongest argument however in favour of the subsequent deposition of these metallic ores lies in the analogy of their mode of occurrence in these beds and in fissure veins, in which the theory of such deposition from subterranean waters is a pretty universally acknowledged fact.[2] The investigation of the mode in which these ores were deposited from circulating subterranean solutions will accordingly be considered with that of the origin of fissure veins; it may be added that the fact stated by several observers to be true of very many different deposits of this class, namely, that these beds are richest in the neighbourhood of fault- or fissure-planes or of eruptive dykes, shows still more clearly the similarity between the mode of origin of these deposits and of certain classes of fissure veins, whilst another significant fact, true of a good many such beds, is that they are richest where they are found uptilted at steep angles, and poorer where they are lying approximately horizontal, a fact that would argue forcibly in favour of the deposition of the ore having been produced by causes subsequent to and quite disconnected from the original formation of the bed.

One of the most typical examples of a bed of this class is exhibited in the *Kupferschiefer*, or copper-bearing shale of Mansfeld, in Prussian Saxony, where mining has been for many centuries extensively carried on (*see also* p. 396). The metalliferous

[1] *Proc. Roy. Soc. of N. S. Wales*, Oct. 2, 1895.

[2] S. F. Emmons, "Structural Relations of Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, xvi. 1880, p. 807.

bed occurs in the *Zechstein*, a member of the Permian formation wanting in this country, but regarded as being equivalent to the Magnesian Limestone of England. At Mansfeld the highest stratum of the series consists largely of unstratified gypsum in which are numerous cavities, locally called *Gypsschlotten*, caused by the solvent action of water upon sulphate of lime. With the gypsum is associated a soft bituminous dolomitic limestone, locally known as *Asche*, and beneath this follows a stratified fetid limestone, below which is the true Zechstein, giving name to the formation. In depth this passes into a bituminous marly shale, the lowest portion of which, seldom above eighteen inches in thickness, constitutes the chief copper-bearing stratum, extending with wonderful regularity for many miles. Of this sometimes only from four to five inches are sufficiently rich to pay the cost of smelting, the proportion of copper in the ores treated varying from two to five per cent. The ore is for the most part an argentiferous fahlerz; but, in addition to this mineral, copper pyrites, copper glance, erubescite, native copper, melaconite, cuprite, galena, blende, copper-nickel and iron pyrites are present. Native silver is but rarely met with, as are also antimony, bismuth, and arsenic.

Under the copper shale is a calcareous sandstone varying in colour from white to gray, which is in part a conglomerate. This, in accordance with its colour, is called either the white layer, *Weissliegendes*, or gray layer, *Grauliegendes*, and sometimes contains copper ores. The regular bedding of these strata is frequently disturbed by faults, which, although they themselves rarely contain ore, appear to have exercised considerable influence on the metalliferous contents of the strata traversed by them. This is indicated by a marked increase or decrease in the amount of ore contained in the beds for considerable distances; the effect sometimes extending as far as their intersection by the next fault.

It is a remarkable fact and one somewhat difficult to account for, that beds of the Permian period should, all over the world apparently, show copper impregnations. Besides this German locality, there are enormous deposits of copper-bearing sandstone in Southern Russia; copper is found in beds of approximately the same age in Great Britain and in various places on the American continent. Some writers have argued that this phenomenon shows that all these strata were deposited in a sea rich in copper salts, but this view seems hardly tenable. It would seem preferable to suppose that the close of this period was attended with earth movements and the formation of fissures, or with outbursts of eruptive rocks, in consequence of which copper-bearing solutions found their way into the still unconsolidated, or but partially consolidated, beds.

At Frankenberg, in Hesse, where, among numerous other German localities, copper occurs in small quantities in the Zechstein group, the true ore-bearing bed consists of a light crumbling clay, and the ore is not, as at Mansfeld, disseminated in microscopic particles, but assumes the form of fossil plants. The stalks, fruit, and leaves of these, are, in some cases, converted into either tetrahedrite or copper glance, while in others the plants have become converted into coal, and are traversed by numerous strings of copper ore. Iron pyrites is rarely associated with the ores of copper in the Frankenberg deposits.

A not very dissimilar deposit occurs, and has been sparingly worked, on the banks of French River, New Annan, Nova Scotia. The Upper Carboniferous strata here consist of red sandstones lying almost horizontal and showing much "false bedding." Above this stratum lies a fissile micaceous sandstone containing imbedded plant remains, now converted into anthracite coal; and associated with these are thin strings of copper pyrites, vitreous copper ore, and iron pyrites, the layer being from one to six inches thick. This bed is overlaid by one of coarse red grits, and then comes a bed of gray sandstone six to ten inches thick on the average, though more in places, containing numerous nodules of vitreous copper ore and of covelline; these nodules generally range in weight from $\frac{1}{4}$ oz. to $\frac{1}{2}$ lb., though they have exceptionally been found to weigh $1\frac{1}{2}$ lbs. The following are analyses, I. of the covelline, II. of bronze-brown copper ore.[1]

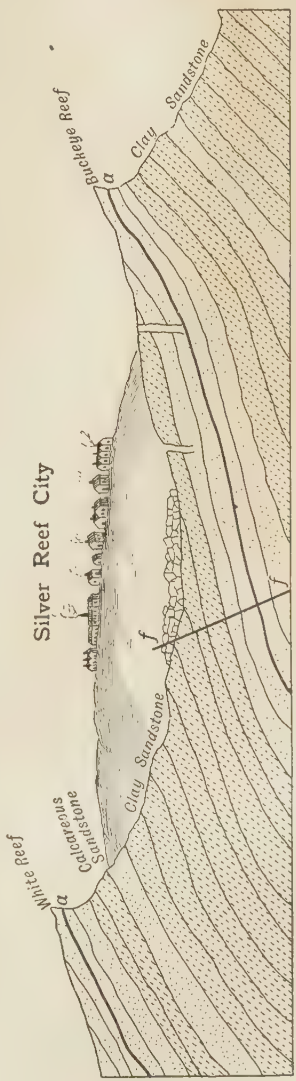
	I.	II.
Insoluble matter	5·78	19·66
Ferric oxide and alumina	3·89	—
Copper	64·11	20·52
Iron	—	25·95
Sulphur	25·64	31·35
Organic matter, lime, magnesia, manganese, &c.	0·58	2·52
	100·00	100·00

There seems little doubt that this deposit was formed by the reducing action of particles of organic matter, or of the gases evolved by their decomposition upon solutions, most likely of sulphate of copper, that traversed these soft fissile beds long after

[1] H. Louis, "Notes on Nova Scotia Mineralogy," *Trans. N. S. Inst. of Nat. Sci.*, 1878, p. 423.

their deposition, and hence that they must be classed in the group now under consideration.

An excellent example is the Silver Sandstone district of Utah, in Washington County, some 320 miles south of Salt Lake City, near the borders of Arizona.[1] The general geological features of the district are shown by the accompanying section, Fig. 11 (taken from the *Engineering and Mining Journal*, vol. xxix. 1880, Jan. 17, supplement), through one of its most productive mines. The formation is of Triassic age, and consists of alternating shales and sandstones. Two of these beds of sandstone, known locally as the "White Reef" and the "Buckeye Reef," whitish-gray to reddish-brown in colour, carrying numerous plant remains in places, and from 300 to 4,000 feet apart in various parts of the field, are impregnated with cerargyrite or horn silver (AgCl) to an average value of some twenty-five ounces of silver to the ton. The ore is not confined to one special bed, but it is limited to a zone thirty to ninety feet wide, anywhere within which the ore may occur; that is to say, the ore occurs in narrow belts now uniting, now being separated by barren rock for a space of thirty feet, now thinning out to reappear again higher up or lower down, or at times faulted by well-marked faulting planes, as shown in the subjoined section (Fig. 12) taken from the quoted paper of



Scale 400 feet to 1 inch.

Fig. 11.—Profile Section across "Last Chance" Mine, Utah.

[1] C. M. Rolker, "The Silver Sandstone District of Utah," *Trans. Amer. Inst. Min. Eng.*, ix. 1880, p. 21.

Rolker. Mr. J. S. Newberry, writing to the *Engineering and Mining Journal*, under date October 23, 1880, states his opinion that the silver and copper which these sandstones contain, were deposited contemporaneously apparently by the agency of the organic matter present and not introduced subsequently, his chief argument being that the beds are argentiferous not only in the neighbourhood of the faults, but that in their extension through the unbroken tablelands to the north they still contain silver, though rarely more than seven to eight ounces to the ton. Nearly all other geologists who have examined these deposits are in favour of the view here adopted, namely, that the silver was introduced subsequently to the formation of the beds. Mr. Rolker (*loc. cit.*) says that the ore, which is horn silver in the upper parts, changes to sulphide of silver at true water level, and holds that it was introduced in the latter form subsequent to the tilting and

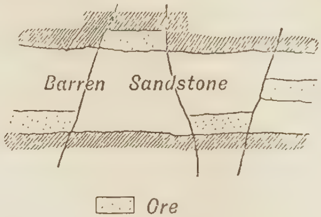


Fig. 12.—Section of Argentiferous Sandstone bed.

faulting of the beds. He points out that the beds are richest near the faults; that the latter are filled with clay, and generally also contain some silver; that whilst the silver is in many spots found replacing the tissue of the remains, in other places stretches 200 feet long, quite free from organic remains, yet very rich in silver, may be met with. Finally, he points out that the facts that the same beds further south carry copper ores, and that the belts of productive sandstone are in places separated by barren strips cannot rationally be explained on any theory of contemporaneous deposition.

The same view is also strongly advocated in an elaborate report on this district contributed to the *Engineering and Mining Journal*, of January 10, 1880. The writer describes this district as follows:

"The beds in it are more or less inclined, and are composed of alternating series of white and yellow, red and purple sandstone and shales, some of which are impregnated irregularly with silver ores either in the form of chlorides or of sulphides. Near the line of the supposed break between the horizontal bed of the plateau and the inclined beds of the silver-bearing districts occur a number of volcanic overflows of basalt, which have the appearance of being the result of a single outflow or eruption, and which appear also to be connected with the presence of these mineral deposits in the inclined beds, which all dip towards the fault. No doubt, the heat and volcanic gases from this lava outburst rendered more energetic the solvent liquids passing through the sedimentary sandstone, containing silver. As this silver-bearing solution approached the surface, its temperature and pressure would be reduced, and as the porous sandstone beds through which it filtered contained large quantities of carbonaceous matter, the silver was precipitated in the insoluble form of sulphides, and these were subsequently in part changed to chlorides above the water-level. In this manner, we may suppose the accumulation of silver ore in these sedimentary sandstones and shales to have been brought about, and many facts seem to confirm this view of the case. The silver occurs as chloride and sulphide, and, occasionally, as native silver, disseminated through the more porous and fissured beds, and especially in the bedding and fracture planes of the sandstone, and coating the bright 'slipped' surfaces of the hard shale beds—locally known as soapstone—where these beds have been disturbed and crushed. Wherever the shale is compact and has not been crushed—that is, wherever it remains in a condition in which water could not pass through it—it contains no silver. And wherever the sandstone beds become very hard, compact, and unfissured, they appear to become poorer, and the silver is confined more largely to the bedding planes. The silver, that at some depth below the surface was distributed with more or less uniformity throughout the ore-bearing bed, appears to collect in the planes between the beds as these approach the outcrop, giving the appearance of the silver 'vein' so called, having split up and come to the surface as thin leaders or stringers of very rich ore. This is not only the well-recognised condition of the silver-bearing beds everywhere near their outcrop, but it is the condition we should naturally expect from the mineral-bearing solution collecting in the bedding-planes, as these offered more available channels near the surface. It is quite evident that the silver we now find coating the polished surfaces of the crushed shales, and filling the cracks and coating the surfaces of the fossilised (petrified) wood frequently found in the sandstone beds, must have come there after these substances had assumed their present conditions. We may, therefore, expect to find in future, as has been found thus far, that the conditions which facilitate the percolation of the silver-bearing solution, where the rocks contained suitable precipitants, will favour the occurrence of ore, and the rocks becoming compact, hard, and unbroken—conditions which would naturally impede the percolation of water—will be found unfavourable to the occurrence of rich ore-bodies. The occurrence of ore in these sandstone beds is extremely capricious, as might be expected from the method of deposition suggested. It occurs in numerous chimneys or *chutes*, and has collected in portions of the beds where ferruginous or carbonaceous matter appears to have attracted it; yet copper, which in many places stains the rocks green, seems, on the contrary, to be an unfavourable indication for silver. The work already done on the silver-bearing reefs has fully demonstrated that the ore is more abundant and richer at certain points than at others, and a most careful examination of each particular property is necessary to determine its value; for while the rocks which contain the ore are as continuous as other sedimentary beds, the occurrence of 'pay' in them appears to be subject to the same laws, conditions, and accidents which have governed the deposition of similar ores in fissure-veins."

It has appeared advisable to quote the above at full length, in order to show the prevailing theories respecting the manner in which these deposits have been formed, as a highly typical example of the class of deposits we are now considering.

One of the most important examples of this class, which must be quoted, is the wonderfully rich gold deposit of the Witwatersrand in the Transvaal. The beds here are comparatively thin beds of conglomerate, locally known as "banket" reefs, from a Dutch word for a kind of almond rock, to which the conglomerate bears a fancied resemblance, somewhat as in English the term "pudding stone" is applied to similar deposits.

These banket beds—erroneously called reefs in the Transvaal—strike approximately east and west, and dip to the south at steep angles from 60° to 85° at the surface, the dip appearing to become rather flatter as the beds go down. The term reef has been so persistently applied to these beds not only by the miners of South Africa, but by most of those who have written on the subject, that it seems advisable to use it here, in spite of the objections to aiding in the perpetuation of a misnomer.

Fig. 13 is a vertical section across the formation at the surface of the Wemmer mine, showing the appearance of the beds when only about forty feet in depth had been attained, and Fig. 14 a more extensive section of the Robinson mine, taken from Hatch and Chalmers' work.[1] At the shallower depth, the beds were soft, consisting of well-rounded pebbles held together by a siliceous and partly ferruginous cement. Near the surface the whole belt, about 100 feet thick, consisting of sandstones, grits and conglomerates, all showed gold to some extent, the conglomerate beds being very rich in places. At that time the banket reef,

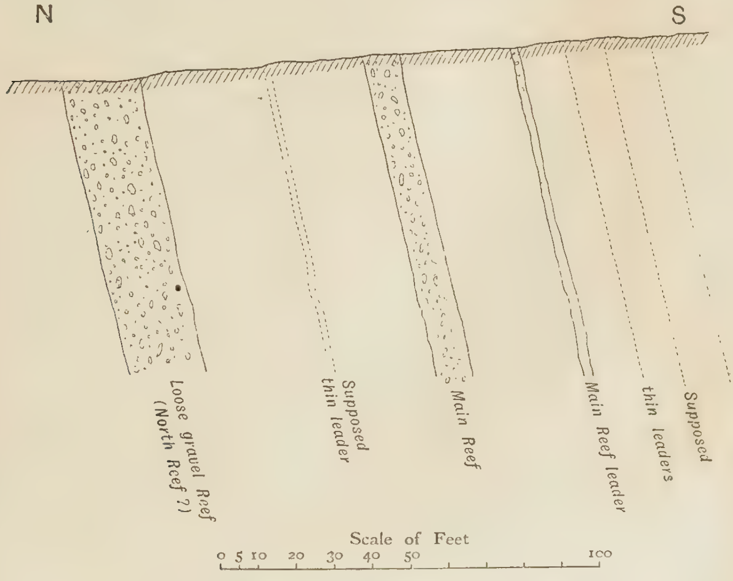


FIG. 13.—Section across Wemmer Reefs at surface.

since called the main reef leader, was alone worked, and yielded about six ounces to the ton. In some places, *e.g.* in the Jumpers' claims, this leader was wonderfully rich, some specimens appearing thickly incrusted with finely divided gold and yielding at the rate of 600 ounces to the ton; it was even then obvious that practically all the gold was contained in the cementing material and very little in the quartz pebbles, the gold being highly crystalline and appearing with perfectly sharp edges under the microscope. As all the quartz pebbles were thoroughly waterworn, it was evident that the gold was not contemporaneous with

[1] F. H. Hatch and J. A. Chalmers, *The Gold Mines of the Rand*, 1895.

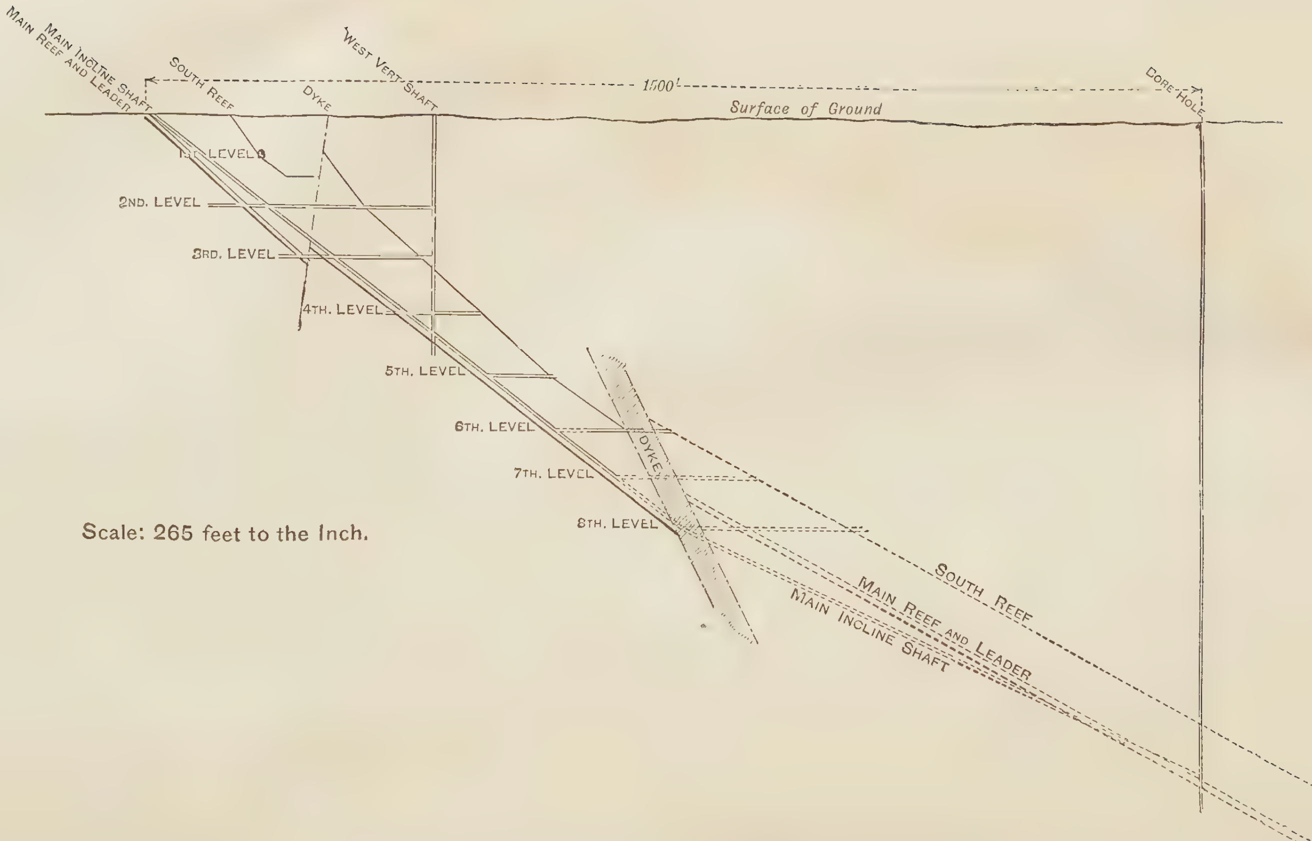


Fig. 14.—Cross Section through Main Incline Shaft West. Robinson G. M. Co.

the bed. Subsequent exploration and very extensive mining operations have greatly increased our knowledge of these deposits, the outcrops of which appear to form the edges of an oval rock basin, whose greatest diameter runs from east to west. A number of separate groups of conglomerate beds are now known, their names from the north edge of the basin towards its centre being as follows:—[1]

Du Preez Reef series.
Main Reef series.
Livingston Reef series.
Bird Reef series.
Kimberley Reef series.
Klippoortje Reef series.
Elsburg Reef series.
Black Reef series.

Comparatively few of these have been worked or found worth working, so that most of them are imperfectly known. Their general characteristics seem to be more or less similar, except as regards the amount of gold contents, and the fact that the outer beds are more steeply inclined than those nearer the centre of the basin. The main reef series is by far the best known, this being almost the only one that carries beds sufficiently rich to be worth working. A number of beds in the main reef series have received special names, and attempts have been made to correlate them throughout the long extension (some fifty miles) in which they are known, but without very much success, as it is by no means certain that the individual beds are continuous. They are very irregular, now thick, now thin; the same bed will sometimes split into several others, and sometimes two or more will coalesce to form one bed; as the entire formation is moreover much broken up by dykes and faults, it is practically impossible to trace a bed for any very great distance. The total number of beds so far recognised seem to be five, named as follows:—

South reef	average	width	$2\frac{1}{2}$ feet.
Middle reef	„	„	4 feet.
Main reef leader . . .	„	„	$1\frac{1}{2}$ feet.
Main reef	„	„	10 feet.
North reef	„	„	2 feet.

[1] Schmeisser, *Ueber Verkommen und Gewinnung der Nutzbaren Mineralien in der Sudafrikanischen Republik* (*Transvaal*), 1894, p. 37.

The widths are very variable, the main reef for instance varying from sixteen feet to a mere thin sheet. The south reef and main reef leader are separated by sixty to one hundred feet of sandstone; there is generally about one foot or two feet separating this leader from the main reef, and some forty feet between the main and north reefs, but the thickness of these partings are as variable as those of the "reefs" themselves. All these reefs are rarely present in any one section, whilst some of them, notably the south reef, seem readily to split into two or three separate "reefs."

At about one hundred feet vertical depth the oxidising effect of surface water commenced to disappear, and unaltered banket was visible. This was much harder and the cementing material was no longer red or brown but greenish-blue in colour, the pebbles being still of white translucent quartz, mostly of medium size, say about that of walnuts on the average. Examination under the microscope has shown that the quartz of these pebbles is a condition of stress caused mechanically by the pressure to which the beds have been subjected subsequently to their formation. The cementing material consists of small grains of similar quartz and the following minerals:[1] Iron pyrites, magnetite, zircon, rutile, muscovite, chlorite, secondary quartz, and metallic gold.[2] The pyrites occurs in rounded and broken crystals as well as in perfectly sharp-edged forms; it seems clear that the former were original components of the conglomerates while the latter have been formed subsequently *in situ* and have acted as a cementing material. The true cementing ingredients are however the chlorite and moscovite; magnetite and rutile are rounded and have been original constituents. Secondary quartz has been deposited in interstices in the conglomerate, and is also found uniting broken quartz pebbles. The gold occurs in microscopic crystals, the forms of which can but rarely be determined with certainty; also in crystalline aggregates, never in rounded, smooth, or flattened grains such as occur in alluvial deposits. It seems to be confined to the secondary minerals, and never to occur in the original constituents of the conglomerate; it is often found intimately associated with the pyrites or encrusting the latter. It is moreover noteworthy that such crystals of pyrites as are found in the original quartz pebbles are very poor or quite barren of gold. The average gold contents

[1] Schmeisser, *loc. cit.*

[2] Hatch and Chalmers (*loc. cit.*) add marcasite, copper pyrites, zinc blende, galena, ilmenite, corundum, and stibnite to this list.

of the unaltered banket, below the depths at which surface enrichment raised them above their true normal, is just about 15 dwt. to the ton. In a communication to the Geological Society of South Africa, Mr. Kuntz[1] gives various reasons for thinking it probable that the dykes and faults that intersect those beds form the source whence the auriferous solution made its way into the beds, and holds that "it may have been that the leaching process went on along the numerous slides and breaks, mostly filled with diabase, which were produced by the tilting up of the whole formation." He goes on to point that "the conglomerates in which the pebbles are lying immediately one on another, are, generally speaking, richer than those in which the pebbles are embedded in a surrounding fine grained cement," giving as an explanation—which is not however wholly satisfactory—that the solution was able to penetrate more easily and percolate more quickly in the former form than in the latter. He also gives it as a generally received opinion that the banket beds are richer in the neighbourhood of the eruptive dykes. Messrs. Hatch and Chalmers, however, say that "they have not been able to find any reliable evidence in favour of the idea locally prevalent that the dykes have acted beneficially on reefs in their immediate neighbourhood in regard to gold-contents." It is noteworthy that these beds have been extremely faulted, overlap faults (*see* page 18) being common in some parts, whilst numerous normal faults also occur, traversing the beds in all directions; some of these are simple fissure planes, others are dykes of all thicknesses up to one hundred feet. The eruptive rocks of which they consist are at times granitic, but are more often diabasic and dioritic, these latter rocks appearing to be closely related to the great sheet of greenstone that covers the country north of the Klip River. Another point of importance is the fact that these banket beds are in places traversed by quartz veins, which are usually extremely rich in gold, as for instance in the claims of the Wolhuter and Jumpers' Companies. The greater richness of the steep-lying, and therefore more violently uptilted, main reef beds, as compared to the flatter lying beds nearer the central parts of the basin, is also a fact that may have great significance in this connection.

From the above description, the genesis of the auriferous banket beds is not difficult to trace in its general broad outlines.

[1] Kuntz, "The Rand Conglomerates," reported in the *Mining Journal*, November 16, 1895, p. 1386.

The close of the Swazischist period was evidently marked by great rock movements, that threw up these strata at steep angles and formed important mountain chains. As one of the results of the subsequent disintegration of these high lands, a series of beds of alternating coarser and finer texture, gravels and sands, was deposited in the area now known as Witwatersrand. This deposition may have taken place on the shores of the ocean, but the absence of fossils and the rapidity of alternation of these beds, together with their comparatively speaking small extent, make it more probable that the scene of their deposition was an inland lake. The absence of water-worn gold is good proof that these beds were not derived from auriferous quartz reefs, unless the somewhat improbable theory be adopted that such water-worn gold was first dissolved and then reprecipitated in the same beds. It is however difficult, if not impossible, to imagine any natural conditions under which such a series of chemical reactions could occur successively within the same area. The unequal distribution and mode of occurrence of the gold, intimately connected, as has been shown, with the cementing minerals of the beds, make it practically certain that the gold was not derived from the waters beneath which the beds were being formed; this latter hypothesis is indeed untenable for very many reasons, even if we had any evidence that such a mode of gold precipitation is ever possible.

These beds, till that time non-auriferous, were subsequently overlaid by others, and in consequence became consolidated, and were next tilted up, these movements being accompanied by the formation of fissures, of faults, and of slips. Concurrently the conglomerate beds were traversed by subterraneous waters carrying gold in solution, which waters penetrated most readily those beds that were most open in structure—*i.e.*, through the gravel beds in preference to those composed of comparatively close-grained sands. Hence we find that the sandstones are but slightly gold-bearing. The other minerals that cement the pebbles together were no doubt formed by the action of the same (probably alkaline) solutions that brought in the gold. It is probable that the intrusion of igneous rocks in this region was more or less directly connected with this circulation of mineralising solutions, the heat and pressure that must have accompanied the intrusion, playing probably an active part in the chemical reactions, or increasing the solvent powers of the waters in depth. Whether the solutions found their way through the fissures that are now veins of gold quartz, through the fault fissures, through the igneous dykes, or through neighbouring strata, is a question that must be left for the present unanswered, as we have no evidence before us by which to decide it; nor do we know either the proximate or the ultimate source whence the gold came. Many theories have been put forward, but none have yet been proved, and it is better to avoid all such highly speculative or controversial problems for the present; sufficient for us to note that we have here a well-marked example of a bedded deposit, in which the metallic ingredient that gives it its value was deposited in it by chemical action, long subsequently to the formation of the bed itself.

The remarkable beds of crystalline sandstone which are worked for lead ore at Commern, in Rhenish Prussia, are of Lower Triassic age, and may be regarded as belonging to the class of deposits at present under consideration. They are situated at the extreme northern end of the Eifel, the ore-bearing rock being a white sandstone of great thickness, which is covered by red sandstones and conglomerates (*see also* page 368). The upper portions of the metalliferous rock, which alone are sufficiently rich to repay the expenses of working, are thickly charged with concretions varying in size from a pin's head to a pea, which are made up of quartzose sand cemented by galena; these concretions are spoken of by the German miners as knots (*knoten*), and form them the name of the bed *Knotten-sandstein* is derived. The roof of the bed, which consists of conglomerate, is not worked for lead, although it sometimes contains pebbles partially coated with galena. In the upper beds large spheroidal concretions of brown ironstone are abundant, some of them being perfectly consolidated, while others are still in a soft state. The nodules contain small quantities of chromium, vanadium, and titanium, the last-named metal being present in largest amount.

The workings are carried on partly by open-cast, and partly by underground mining. When the over-burden does not exceed 100 feet in thickness the metalliferous bed is stripped, the overlying rock being removed by a series of terraces. When, however, in following the deposit to the dip, the covering becomes of a greater thickness than that indicated, levels are driven into the bed, and the ore is won by a system of irregular pillar-working, not unlike that employed for winning the thick coal of South Staffordshire. The rock, although soft, usually stands without timber, but when once broken from the mass, it crumbles so readily that the nodules of impure lead ore are separated from the unproductive sand by the use of drum-sieves. This sifting is carried on in the mine itself by manual labour, the nodules of lead ore alone being sent to surface, while the sand separated from them is employed for filling the exhausted workings. The nodular galena mixed with sand is subsequently stamped and dressed in the usual way, but the carbonate of lead, a considerable amount of which is present in the rough ore, is to a large extent lost in the operation. The annual production of lead from this district is very considerable, and the lead produced from the ores contains from $2\frac{1}{4}$ oz. to $4\frac{1}{2}$ oz. of silver per ton. Lead ores occur under somewhat similar circumstances near Gerolstein in the High Eifel, and in many other German localities, as well as in Nottinghamshire and Leicestershire in this country.

In the copper-bearing Lower Keuper sandstones of Alderley Edge, Cheshire, carbonate of lead and some other oxidised ores of that metal, such as vanadinite and pyromorphite, are found, and here, as at Commern, they are sandstones to a large extent made up of crystalline grains of quartz.[1]

The presence at Commern of nodules of clay ironstone in some of the upper beds, together with the fact that the grains of sandstone of the lead-bearing horizon are frequently covered by a crystalline deposit of quartz, which has converted them into more or less perfect crystals, indicates extensive chemical action, in which water has performed an important part. Such deposits can, therefore, only be regarded as precipitations from metalliferous solutions collected and transported by aqueous agencies, either from the rock itself, or from rocks in its more or less immediate neighbourhood.

Class II.

Epactic Deposits.

This class of deposits is distinguished by the common characteristic that all of them were formed subsequently to the rocks in which they are encased, so that the rocks surrounding, or on either side of them, are older than the deposits themselves Hence it is always possible to meet with fragments of the encasing rocks in the deposit itself, an impossibility in the case of symphytic deposits. Epactic deposits are always less uniform

[1] For description of various crystalline sandstones see paper by J. A. Phillips, *Quart. Jour. Geol. Soc.*, xxxvii. 1881, p. 6.

in their mode of occurrence and less regular in the distribution of their metallic contents than are those of the former class They may be divided according to their forms into two subclasses, the regular or tabular deposits which may be generically spoken of as veins, and into irregular deposits which have no definite shapes and are of very varying dimensions. With the exception of iron ore, as already pointed out, the larger proportion of metalliferous minerals is derived from deposits belonging to this class. Fournet has remarked with regard to mineral veins that metals having become of the first necessity to man, he would naturally attach great importance to metalliferous minerals; and that it is to the study of their various modes of occurrence, and of their relations to phenomena affecting the adjacent rocks, that the science of geology owes its birth. Certain is it that these deposits have very long been carefully studied, although our knowledge of them is still very imperfect, and it is only within the last few years that it seems to have been partially placed upon a scientific basis.

SUB-CLASS I. VEINS.—This division is characterised by being more or less tabular in form, that is to say, that one dimension is very much less than the two others, or in other words they are thin compared to their extension in length and depth, due to the fact that they are deposited in or originate from fissures or planes of disruption or of weakness in the rocks in which they occur. As a general rule the sheets which they form are distinguished from beds in that their position approximates more nearly to the vertical than to the horizontal. Not only do they generally thin out or split up as they run out towards their ends, but they also exhibit throughout their extent considerable irregularities due as well to unequal breadth as to difference in their contents, and changes in their direction and inclination, whilst in common with the rocks in which they occur, they are subject to faulting similar to that already referred to under the head of symphytic deposits. The rock in which a vein is enclosed is called the *country* or *country rock.* Those portions of the country in contact with the vein are known as its *walls* or *cheeks*, and when the vein is not vertical that which is above it, is its *hanging wall*, while that below it is its *foot wall.* The horizontal direction of a vein is called its *strike* or *course*, while its greatest inclination to the horizon is its *dip.* In some of the mining districts of England the inclination of a vein is measured by its *hade* or *underlie*, or angle of variation from the perpendicular, as in the case of beds.

A layer or sheet of argillaceous material often extends along one or other or both of the walls of a lode, between the vein itself and the enclosing country rock. This, which mainly consists of an unctuous clay, is called its *selvage* or *flucan*, in America *gouge*, and is sometimes slickensided or scored with curved, crooked, and unconformable striæ.

Bands of compact siliceous rock often occur in the immediate vicinity of the fissures enclosing mineral veins, and more frequently accompany tin ores than ores of copper. This hard quartzose material occasionally contains a sufficient amount of tin to repay the expenses of working, and when this is the case it is generally regarded as forming part of the lode. When, on the contrary, it contains no tin ore, or not a sufficient amount to pay, it is called *capel* by Cornish miners, and is regarded as a portion of the country rock. It is therefore often difficult to define the difference between an ordinary tin veinstone and a tin capel. Microscopical examination of thin sections of capels shows that they are often mainly composed of a quartzose base, throughout which crystals of tourmaline are thickly disseminated. Sometimes, and particularly when they occur in clay slates, capels consist principally of a mixture of quartz and chlorite. In other cases, both tourmaline and chlorite are present in the same capel, together with innumerable microscopic fragments of almost unaltered country rock. There can be but little doubt that in the majority of cases the capels of the miner are the result of extreme metamorphism of the country, produced by the agency of solutions from which the materials forming the lode itself were deposited. The replacement of crystalline and other rocks by quartzose pseudomorphs has been observed in connection with metalliferous veins in various parts of the world.

A *cross-course or cross-vein* is a vein intersecting another of greater geological age which it frequently displaces from its original course. Cross-courses are sometimes, but not always, metalliferous; while, in many cases, they are composed either of quartz or of flucan. Cross-courses are often fissures filled with matter introduced by purely mechanical means, such as fragments of the wall-rock from above, or *débris* produced by the friction of their sides one against another. This sliding motion of one side of a fault over the other causes a violent trituration of the walls, and gives rise to friction surfaces which exhibit smooth and sometimes even polished faces, on which there are frequently parallel scratches or furrows indicating the direction in which the motion has taken place (*slickensides*). The rubbing together of the surfaces of such dislocations produces a fine powder, which, with water, ultimately becomes transformed into a soft clay or flucan; the origin of selvages as well as of many cross-courses may be often thus explained. The horizontal dislocation of a lode is called a *heave*, while a vertical displacement is known as a *slide* or *leap*. The *outcrop*, *basset*, or *back* of a vein is that portion of it which appears at the surface. The direction of the outcrop does not coincide with that of the strike unless the vein is vertical or the surface of the ground horizontal, precisely as in the corresponding case of beds.

Veins are exceedingly variable in thickness, some having a width of many fathoms, while others are represented by the filling of the most minute crack. The longitudinal extent of veins, like their thickness, is very variable; but as a rule, the widest are the most persistent both in length and in depth. Some metalliferous veins have been traced for a distance of several miles.

GROUP *a*. FISSURE VEINS.—These are known by many different names in various English-speaking mining districts, such as true veins, lodes, reefs, ledges, rake veins, right veins, &c. A fissure vein may be defined as a fissure of indefinite length and depth, filled or associated with mineral substances, and often containing metalliferous ores, traversing the enclosing rocks independently of their structure, and which is not parallel to their foliation or stratification. Veins are distinguished from dykes in that the latter are intrusive sheets of igneous rock that appear to have forced their way upwards through the strata in a state of fusion, from which they have subsequently cooled down and their mineral constituents (generally non-metallic) have crystallised out. Fissure veins are generally admitted to have originated in fissures or dislocations caused by extensive movements of the earth's crust, and are therefore believed to extend indefinitely in depth. The two walls of a vein do not always coincide in level, one having often risen or sunk, as compared with the other; so that the vein fissure is frequently at the same time a fault.

Fig. 15 is an ideal transverse section of a true or fissure vein pursuing its course across the planes of bedding, although cutting through them at a very acute angle. A true vein may at some part of its course coincide with the dip of the strata, or it may even send out spurs or branches following the lines of dip or cleavage, as shown in the figure. In studying the genesis of true mineral veins, connected as these always are with a fissure, it is necessary to examine separately the mode in which the fissure was originally formed, and that in which it subsequently came to be filled with mineral matter.

The walls of metalliferous veins[1] are seldom parallel to one another for any considerable distance, and their width consequently varies in different parts. This will be understood when it is remembered that the original fissure, which often passes through rocks of different degrees of hardness, never follows an absolute plane, and consequently that any movement of one of its sides must necessarily result in an opening of unequal widths. This will be clearly seen on referring to the annexed illustrations, in which Fig. 16 represents a line of fracture, *a b*, traversing the country rock, horizontally. In Fig. 17, *a b* is the same fissure, and if we were now to divide the paper by cutting it into two parts along this line, and to slide the lower portion from *a* to *a′*, its upper and lower edges would meet at the points *o*, leaving

FIG. 15.—True vein *a*, sending out a branch *b*, corresponding with bedding.

an irregular opening at *c* and lenticular spaces at *d*. If instead of sliding the lower portion of the divided paper to the right hand, we move it towards the left, as in Fig. 18, for about the same distance as it was previously moved to the right, we obtain two lenticular spaces *c*, and an irregular opening *d*. The foregoing examples serve to show to what slight circumstances considerable variations in the character of an opening between the uneven surfaces of a fissure may be due, and explain one of the most frequent causes of the inequality observed in the width of mineral veins.

The elevation or depression of one of the sides of a more or less undulating fissure will necessarily give rise to similar results, and by this means irregularities in width will be produced similar

[1] When the word vein is used without qualification, a true vein is meant.

to those caused by horizontal movements of the country rock. In order better to understand this we may regard the foregoing diagrams as representing a fissure in transverse instead of in horizontal section.

It is worth mentioning that this view seems to have been first put forward by John Leithart,[1] who says :—" If the fissures have a uniform inclination, then there will be formed between their sides chasms of uniform width, ... but if the vertical course of the fissures be inflected, then will an irregularly formed cavity be produced between the sides of the fissures, the cavities being

FIG. 16.

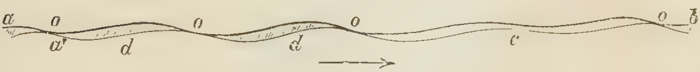


FIG. 17.

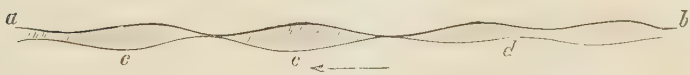


FIG. 18.

Opening of fissures; after De la Beche.[2]

much larger in those parts that have the greatest inclination." He illustrates his arguments very clearly by means of diagrams.

Modes of Occurrence.—Among all the various forms in which metalliferous deposits are known to occur, true veins may be regarded as among the most important, since they are not only the usual source of many of the more valuable metals, but they also, from their persistency and comparative regularity, afford scope for systematic and continuous workings.

As a general rule, lodes are associated in clusters approximately parallel to one another, thus forming groups, which sometimes traverse the same district in different directions. An examination of the intersection or displacement of different veins at the points where they are divided either by cross-veins or by one another, shows that some of them are older than others; and thus, by observing which of them, respectively, cross others

[1] J. Leithart, *Practical Observations on Mineral Veins*, Newcastle, 1838, p. 12.

[2] *Geological Report on Cornwall*, &c., 1839, p. 317.

or are crossed by others, their relative ages may be determined. In this way Mr. Carne was enabled, many years ago, to divide the veins of Cornwall into eight distinct groups according to their relative ages. The most manifest division, however, of Cornish veins is into those running east and west, usually yielding tin and copper ores, and lodes of which the direction is nearly north and south, commonly producing ores of lead.

Metalliferous veins are of more frequent occurrence in the older rocks than in the more recent, and the ores of certain metals are to a large extent confined to particular groups of rock. Lodes are most frequently found in districts where sedimentary beds have been penetrated by porphyries and other igneous rocks, and they are consequently more abundant in mountainous countries than in plains. Igneous rocks thus penetrating sedimentary beds are, as well as the beds themselves, frequently traversed by ore-bearing veins. Lodes are also often more productive in the vicinity of the junction of dissimilar rocks than elsewhere. This is particularly observed in Cornwall, where veins of tinstone and copper ore occur both in granite and *killas* or clay slate, but they are seldom found to be productive at any considerable distance from the junction of the two rocks.

The dip of metalliferous veins usually approaches more nearly to the vertical than to the horizontal. In the north of England their inclination from the vertical rarely amounts to more than 10°, while although averaging more than this in the mining districts of Cornwall, their mean inclination may be taken at about 20° from the vertical or 70° from the horizontal. The same lodes, within short distances, often vary considerably in direction, width, and dip, and they frequently split or divide into *branches* both in length and in depth ; these branches may or may not again unite. If, as in Fig. 19, a lode *a* encloses a mass of the country rock, the included fragment *b* is called a *horse* or *rider*.

The dip of a lode is not always continuously in the same direction throughout its downward course, but, on the contrary, it sometimes becomes gradually vertical, and finally turns over, assuming an inclination in a direction exactly contrary to that with which it originally started from the surface. Numerous examples of veins varying greatly in their dip, were afforded by the Fowey Consols Mines, Cornwall, where some of the lodes divided, in depth, into two parts, apparently without again coming together, while few of the intersections, or junctions of one lode with another, were attended by any displacement of either of them.

Intersections and Faults.—It sometimes happens that veins meet one another without intersection or displacement; in such

FIG. 19.—Horse, or rider.

cases it is often assumed that the fissures are of the same age, and that they were contemporaneously filled with veinstone or ore. When veins meet at a very acute angle, they occasionally

FIG. 20.—Diverging veins.

run parallel to one another for a considerable distance and subsequently diverge, as seen in Fig. 20. In other instances, after running parallel to one another for a greater or less distance

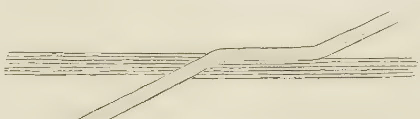


FIG. 21.—Veins crossing without displacement.

they ultimately cross, the newer vein passing through the older one as shown in Fig. 21. When a vein is intersected by a fissure, or by another vein of more recent age than itself, a fault or displacement is often the result, in which case the plane of the older vein on one side of the line of fault no longer coincides with its extension on the other side as shown in Fig. 22, in which *a* represents the dislocated vein and *c* the fissure or vein by which it has been intersected.

It very frequently happens that a vein fissure is itself a fault, and in such cases the difference of level which occurs between similar strata on its opposite sides, is often called the throw of the vein. As a general rule this throw is but small; fault fissures, that have produced a very great throw of the strata, are but rarely filled with metalliferous minerals or converted into veins. The amount of throw, however, in some of the lead veins of the north of England is as much as 160 feet.

All faults have been produced by a sliding of the country rock on one, or on both, sides of the fissure along which the

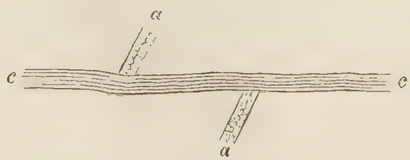


Fig. 22.—Vein displaced by a cross-course.

movement has taken place. This may often be explained by a slipping down of its hanging wall upon its foot-wall in the direction of its dip; sometimes, however, the country on the hanging wall side may either have been forced upwards, or the two walls may have experienced unequal or contrary movements as in the corresponding cases of beds (*see* page 16). In other cases the walls may have also experienced horizontal displacement.

The extent of the horizontal displacement of a lode by the sinking or rising of the country on one side of a fault, depends not only on the amount of dislocation it has experienced, but also on the angle which the direction of motion makes with the plane of the vein intersected. When this angle equals zero the effects, horizontally, of the fault will be imperceptible, and can only be recognised by similar portions of the intersected vein being found at different altitudes.

Complicated cases of faulting can only be understood after the position of the planes of the dislocated lodes has been exactly determined, and it has also been ascertained along which of the various fissures displacement has taken place, as well as the direction of the several movements.[1]

The parallel lodes *a b*, Fig. 23, seen in horizontal section, are apparently heaved in contrary directions by the more recent vein *c*. This will be understood when it is remembered that the two lodes dip towards one another, and that any elevation of the country on the upper side A, of the cross-vein *c*, or any depression of the rocks on the lower side B, would produce the effect observed. It is further obvious that, in the case of lodes dipping in contrary directions, the results of an elevation or depression of the country on either side of the fault will be different to those produced by similar movements on lodes dipping towards one another.

When a country is traversed by fissures, crossing and dip-

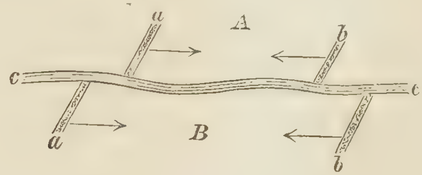


FIG. 23.—Veins, dipping towards one another, displaced by a cross-course.

ping in different directions, great care is often required in order to understand the relative positions of the several parts after having been disturbed by faults, and when the surface has been subsequently ground down by erosion to an approximately common level. As an illustration let us suppose Fig. 24, after De la Beche,[2] to represent such a case, *a b* being the present level of the country, and b^1, b^2, b^3, b^4, and b^5 representing so many different veins. Let this country be dislocated along the plane of the section so that *a′ b′* on the side B is lifted vertically above *a b* on the side A, or, what amounts to the same thing, the side A has sunk the same distance below the level of *a′ b′*. It will be seen that although the amount of vertical elevation has been common to all of the lodes, they now occupy on the surface *a b* very different positions and distances from one another than they did

[1] Those specially interested in this subject should consult S. C. L. Schmidt, *Theorie der Verschiebungen älterer Gänge*, Frankfurt, 1810. C. Zimmerman, *Die Wiederausrichtung verworfener Gänge, Lager, und Flötze*, Darmstadt, 1828. R. v. Carnall, *Karsten's Archiv.* ix. 1832, p. 3. C. Combes, *Traité de l'Exploitation des Mines*, Paris, 1844. A very complete bibliography of the subject will be found in a paper on fault rules by F. T. Freeland, *Trans. Amer. Inst. Min. Eng.*, xxi. 1892, p. 491.

[2] *Geological Report on Cornwall*, &c., p. 298.

originally, according to the various dips intersected by the line of surface. This becomes still more evident on referring to the plan, Fig. 25, supposed to be taken at *a b* after the country on the side B had been removed by denudation to the same level. The letters and figures of reference correspond in plan and section,

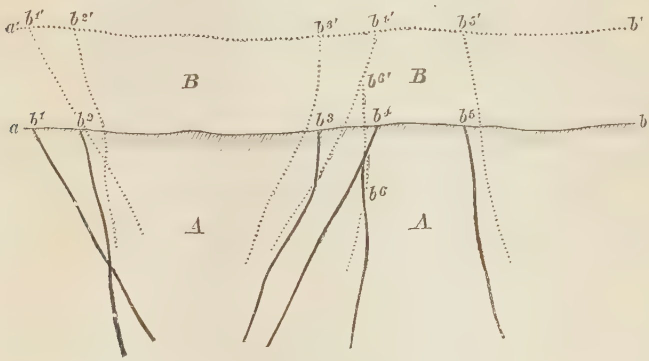


FIG. 24.—Effects of a fault on veins with different dips; section.

and it will be found on comparing the two that the veins b^1, b^2, and b^5 are shifted to the right, on the side of the dislocation marked B, while b^3 and b^4 are moved to the left; the branch b^6 on the other hand, which does not reach the surface on the side A, appears on the side B at the level *a b*.

As in the case of beds, a geometrical rule can be given for determining the direction of horizontal displacement, caused, be it

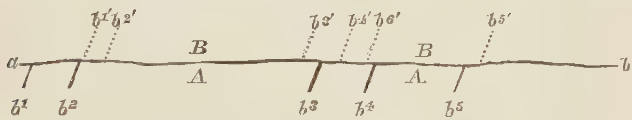


FIG. 25.—Effects of a fault on veins with different dips plan.

remembered, by vertical throw in a diagonal direction, when the dip and strike of the vein and of the fault plane respectively are known. The same general rule holds good that the side of the country, and with it of the vein that is on the hanging wall side of the fault, has been thrown down relatively to the other side, and as the direction of the horizontal displacement depends on that of the vertical throw, a geometrical law can be stated, which, as in the corresponding case of beds, holds for the vast majority of instances. The following is in substance Zimmerman's rule, stated however in a slightly different and perhaps simpler form: If in driving a level along a vein a fault be met with it will be necessary to set out in plan the level, the strike of the fault on that level, and the line of intersection of the planes of the vein and fault. Then the heaved part of the vein should be looked for on that side on which the plan of the intersection makes the largest angle with the plan of the fault.

In Fig. 26 let AB be the plan of a level that is being driven along a vein dipping 75° as shown, the level proceeding in the direction AB. At B a fault striking in the direction CC', and dipping 50° as shown, is met with. It is required to know whether it will be necessary to drive to the right hand or to the

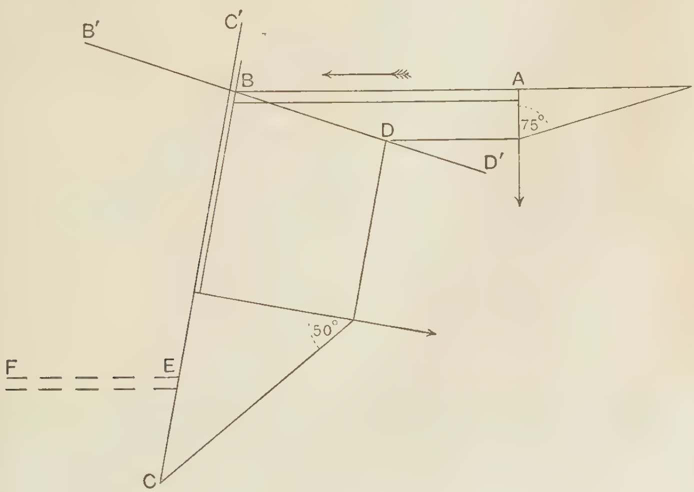


Fig. 26.—Plan of intersection of vein and fault

left to find the heaved portion of the lode. Determine by construction a point D on the intersection of the fault and lode at any convenient level below the plane ABC. Join BD, and produce it both ways to $B'D'$; then $B'D'$ is the plan of the intersection, and as the angle $B'BC$ is larger than $B'BC'$, the heaved portion of the lode may be expected to lie towards C, as for instance at EF. This would be called a left-handed heave, and it will be noted that in whichever direction the fault be approached, whether in that of AB or of FE, the heave will always be to the left. A heave in the opposite direction would similarly be called a right-handed heave. It will easily be seen that if either the vein or the fault plane had been dipping in the opposite direction to those shown, the heave would have been a right-handed one, except in the rare cases of overlap faults. In Figs. 27 to 30 four cases of faulting are shown in vertical cross-section. In these the strikes of the vein and of the fault are parallel instead of crossing each other. A level driven on these veins would never meet the fault, which would only be crossed in sinking. Hence Zimmerman's rule does not apply, and the ordinary rules of bed faulting have to be used. In Fig. 27 the dips of fault and vein are in contrary directions, and in Fig. 28

Fig. 27.

Fig. 28.

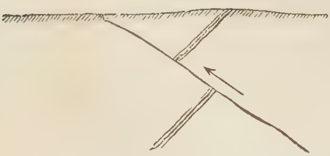


Fig. 29.

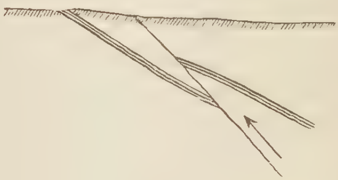


Fig. 30.

Slides or leaps.

in the same direction, these both being normal faults as above defined, *i.e.* faults in which the hanging wall side of the fault has moved downwards relatively to its foot-wall side; it will be seen that as the result of this movement there is a space in the direction of the movement, between the divided portions of the vein, from which the vein has slipped away as it were, and which space if projected on a horizontal plane would represent a sterile area, the width of which will vary with the amount of displacement. In Figs. 29 and 30 a reverse or overlap fault is shown in which the hanging wall of the fault has moved upwards relatively to the foot-wall; the result, as in the similar case of beds, being that the vein overlaps itself, and a horizontal projection would show two veins superimposed over a certain space the width of which depends upon the amount of dislocation. In Fig. 30 the dips of fault and vein are in the same, in Fig. 29 in opposite directions. It cannot be too clearly understood that the movements that have caused faulting, whether of beds or of veins, are identical in every respect, and that the effects upon the deposits are only different inasmuch as the angles of inclination of these two classes of deposits are apt to differ. A steep-lying bed is affected like a vein, and a flat-lying vein like a bed, and the proper rules must therefore be applied with this consideration. In all doubtful cases the leading principle must be borne in mind, that the hanging wall side of the fault has, in at least nine cases out of ten, moved downwards relatively to the foot-wall side.

When the throw has been produced by a fissure, of which the position is exactly vertical, the direction in which the movement has taken place can only be determined after a careful study of the sequence of the rocks on both the hanging and foot-walls of the lode, and their correlation with the same rocks where visible in undisturbed ground.

It has been already stated that the relative ages of veins and systems of veins in districts where they cross one another, may

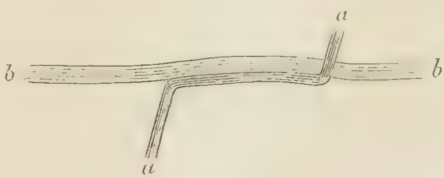


FIG. 31.

be ascertained by observing which of them intersect others, or are severally intersected by others; and that the intersection of a vein by another of more recent date is often attended by a displacement or heave of the former. In comparatively rare cases, however, the more recent vein appears to have been displaced by the older one, although this is not in reality the case.

The more recent vein *a* in Fig. 31 would appear to have been displaced by the older one *b*, which it finally intersects. The true explanation of this phenomenon is, however, that the fissure of the vein *a*, following the lines of least resistance, has taken its course for some distance along one of the walls of the older vein *b*, and has then crossed it, without causing any horizontal displacement.

Instead of forming an angle and following one of the walls of an older vein, the newer one occasionally, although still more exceptionally, enters the older vein by a fissure not extending directly across it, but communicating with longitudinal cracks along the axis of the vein itself, which subsequently unite with a fissure traversing the country on the opposite side. Fig. 32 represents a case of this kind, where the more recent vein *a*, enclosed in the older one, follows for a short distance the course of the vein *b*, by which it would at first sight appear to have been displaced.

When a vein fissure becomes somewhat abruptly contracted so as to be represented by a mere crack in the country, the lode is said to be *nipped*. Branches which leave a main lode and fall away into the country rock are called *droppers*, while those which, on the contrary, fall into the lode from the surrounding rock are known as *feeders*. The character and direction of these offsets from a vein are carefully watched by the practical miner, who, from their general appearance and position, often forms his opinion with regard to the portions likely to yield the largest amounts of ore.

Mode of Formation of Fissures.—It cannot be said that we have to-day any certain knowledge concerning the mode in which

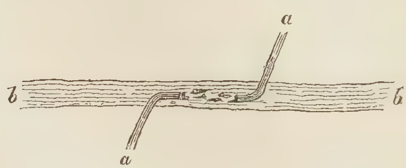


Fig. 32.
Veins apparently displaced by older ones.

the fissures, which by subsequent mineralisation have produced our metalliferous veins, have been formed. Modern geological research appears to indicate that their probable cause has been the gradual contraction through cooling of the fluid or semi-fluid nuclean portion of the globe. The solid and more or less brittle envelope of rocks that constitute the crust of the earth, being compelled by the action of gravity to adjust itself to this contracting nucleus, and being thrust into a superficial area less than that which it previously occupied, would be thrown into folds and rugosities, whilst owing to the brittleness of the strata, even the slowest of such movements would be attended with a certain amount of fissuring, which obviously would be likely to follow a direction parallel to that of the plications, whilst faults and overthrusts might result at the same time. Such contractions causing the violent thrusting downwards of solid rock masses would probably exert heavy pressure on any molten rocky matter that might be met with, producing eruptions of the latter either along the fissures thus formed or through any other planes of weakness, and the expulsion of this molten matter would thus produce empty spaces that would have to be filled and thus afford room for further movements. It is also possible that the pressure produced and heat generated by these dynamic movements might melt some of the deeper seated rocks and thus further assist such movement. At any rate the downward pressure of the crust as it fits itself to the shrinking nucleus must set up enormous compressive strains in the rocks of the earth's crust, whilst the irregularity of the movement must cause great torsional stresses. To the mechanical action of these two forces, compression and torsion, it is probable that most of the fissures in the earth's crust are due. Daubrée,[1] who has given much study to this question,

Fig. 33.—Plan of Devon and Cornwall, showing four main fissure systems.

has shown experimentally that a torsional strain set up in an elastic yet brittle homogeneous body such as a sheet of glass, will produce two systems of fracture at right angles approximately to each other, and refers the systems of cross fissure veins, that characterise most mining districts in which vein mining is actively carried on, to the action of such forces. Cornwall offers an excellent example of such a system of fissures approximately at right angles to each other. This may be clearly seen in the generalised plan of Devon and Cornwall, Fig. 33, copied from De la Beche.[2]

Daubrée's experiments, which have recently been repeated by

[1] *Études Synthétiques de Géologie Expérimentale*, A. Daubrée, 1879, p. 307.

[2] H. T. De la Beche, *Report on the Geology of Cornwall*, &c., p. 309.

G. F. Becker,[1] show clearly that torsional strains tend to produce two sets of approximately parallel fractures, each at angles of 45° to the axis of torsion, and therefore at right angles to each other, the tendency to form a right angle being however liable to disturbance by several attendant circumstances (Daubrée, *loc. cit.*), such as want of homogeneity in the substance experimented on and the unequal manner in which pressure acts upon apparently similar portions. In either case one of the two systems of fissures may greatly predominate. Mr. Becker holds that the angle between the two series of fissures depends on the amount of distortion that may have preceded rupture ; in a brittle substance, which is fractured before it has been deformed to any considerable extent, the two series of fissures will cross at right angles, whilst if circumstances prevent the fissuring from taking place until deformation has reached an extreme limit, the angle between the direction of the force and that of the fracture may be 50° or even 60°, large angles always appearing to mean great preliminary deformation. One of Daubrée's most important observations is the fact that, whilst some of the fissures continue right across the glass plate, others, which cross the former, are so to speak deflected by them, so that instead of forming a continuous fracture they present a series of short discontinuous parallel ones, crossing the former series and making with them a series of steps or zigzags. Although these two systems must have been produced within a very brief period, the above deviation might lead to the supposition that the interrupted fissures were formed subsequently to the continuous ones. Whence it would appear that fractures, which geologists would call contemporaneous, can present the appearance of having been produced at different periods ; and moreover that, contrary to the generally received opinion, the more recent fracture has undergone a dislocation caused by the older one (*cf.* pages 71, 79).

Daubrée has also studied experimentally the effects of pressure, and has shown that a prismatic block of semiplastic material (A) subjected to vertical pressure A tends to split along, plane F inclined at about 45° to the direction of the pressure ; a triangular prism, which was faulted to a considerable extent, being split off, and the throw of the fault being normal. Other planes of fracture f at right angles to the main one are also produced (*see* Fig. 34, reproduced from Daubrée). It is most important to note that, besides

[1] *Trans. Amer. Inst. Min. Eng.*, "The Torsional Theory of Joints," xxiv. 1894, p. 130.

the principal fractures F, a series of very numerous fine rectilinear and parallel fissures R are shown on each face of the prism, which has undergone slight deformation; these fissures are extremely thin, many of them appearing as mere striæ, but very sharply defined. They form a very close network, there being sixty to seventy in either direction in a space of 90 to 120 millimetres (3·5 to 4·7 inches), whilst microscopic examination shows still

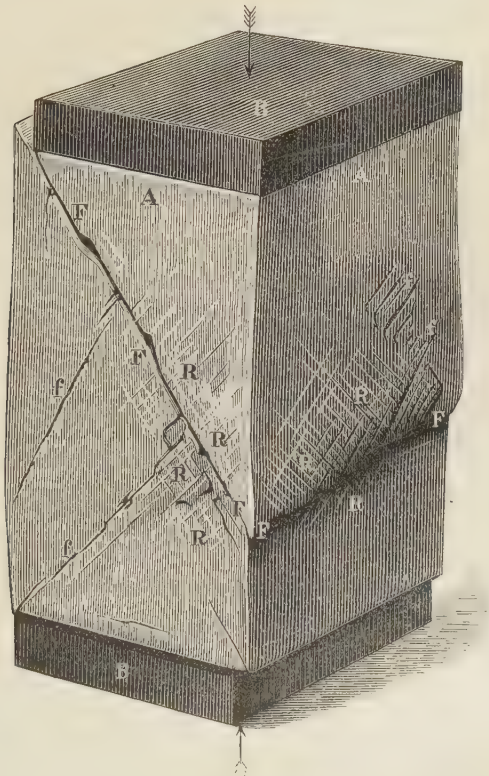


FIG. 34.—Fissures produced by pressure; after Daubrée.

finer striæ between the well-marked fissures. The mass thus fissured is thereby rendered cleavable.

The same author has also shown that horizontal pressure is equally capable of producing faults, it being noteworthy that all the faults which he figures as having been produced in this way show reversed throw, or are overlap faults.

It can hardly be doubted that these forms of strain, namely, torsional or rotary, horizontal and vertical, must be produced in the earth's crust by the dynamic movements of the latter, and though most phenomena are probably due to their simultaneous action, it is quite possible that under certain circumstances, one or other would predominate, and that the above experiments may fairly be taken as indications of the way in which fissures and faults have been produced.

The faulting that so often takes place along fissure planes is therefore in all probability a continuation of the dynamic action that produced the fissures, or else is a complex phenomenon such as the resultant of a shearing strain produced by the vertical thrusts to which the rock masses were subjected perhaps after being fissured by torsional strains.

Many lines of faulting are in places mineralised and then form true fissure veins. A good example is the great fault of Healey Weld in Durham, some two miles long, along which numerous lead mines are situated.

The depth to which such a plane of fracture can extend is difficult to estimate. Heim placed it at about 15,000 feet. It is certainly far deeper than any portion of the earth's crust that has been or is ever likely to be reached by mining operations. It is not possible that planes of fracture can permanently extend to depths at which rocks are in a plastic state, for any fissures formed under such conditions would at once be reunited. Whilst gaping fissures of considerable width are known to exist and can of course remain open in the superficial portions of the earth's crust, the pressure at great depths below the surface would prevent such fissures from remaining open, if even they could form at all.

It would appear that in the geological history of the earth, there have been alternate periods of marked dynamic movements and of absolute or comparative freedom from such disturbances. The shrinkage of the heated nucleus must be continuous, but probably this shrinkage will need to continue for a considerable period, before the forces thereby called into existence can acquire sufficient intensity to produce movements of the importance that we have been considering over great areas and in enormous rock masses. It would still seem to be doubtful how far earthquakes can be considered to be due to such shatterings and dislocations of the earth's crust, although most geologists appear inclined to regard them in that light.

Other fissures of lesser magnitude than these fracture planes may either have been formed like them, as already pointed out, or else may be due to contraction, caused it may be by the cooling of a mass of rock, of igneous rock more especially, as it gradually approaches the outer surface of the earth's crust, whether by upheaval or by the denudation of superincumbent strata. Contraction fissures may also have been caused by the drying or dehydration of a bed of rock. Contraction fissures, however caused, may be expected to be less extensive than dynamic fissures. Such joints seem to be especially common in limestones. Obviously in rocks, which like limestones and dolomites, are soluble with comparative readiness in water containing carbonic acid, any fissures, however formed, will very readily be enlarged by the erosion of their walls by the water circulating through the fissures, and joints that might be so fine as to escape notice in less soluble rocks, would thus assume considerable importance in these more readily soluble strata.

Structure of Veins and Composition of Veinstones.—Speaking generally, the larger proportion of every vein fissure is occupied by *gangue* or *veinstone*, these being the terms applied to the non-metalliferous portions which almost invariably accompany ores of the valuable metals in a vein or lode.

The most constantly occurring substance in veinstones is quartz, which is probably present to some extent in all mineral veins. This quartz is usually either crystalline or crypto-crystalline and contains numerous fluid cavities; it is sometimes also concretionary. Beautiful specimens of crystallised quartz are obtained from the druses, or *vughs*, which are frequently met with in veins. After quartz, carbonate of lime is the mineral which most frequently forms one of the constituents of veinstones; it is commonly crystalline, and often passes into brown spar or dolomite. Fluor spar and heavy spar are also minerals which frequently occur in veinstones. In many cases these, either singly or together, constitute for considerable spaces the entire filling of vein fissures without any admixture of metalliferous ores.

If thin sections of veinstone be examined under the microscope with polarised light, they will be found to consist largely of crystals or crystalline grains; but, to the unassisted eye, they sometimes appear to be compact, or only slightly granular. Through this amorphous or granular ground-mass metalliferous ores are disseminated in patches, laminæ, or crystals; and when crystallised forms prevail, the physical constitution of the veinstone is analogous to that which among rocks is known as a porphyritic structure.

Many lodes enclose fragments of the surrounding country rock; these, which are sometimes angular and at others rounded, are cemented together either by ordinary veinstone or by metalliferous ores. The latter was the case at Relistian, in Cornwall, where rounded pebbles of a dark-green chloritic schist were found cemented into a conglomerate by a mixture of oxide of tin, chalcopyrite, and quartz.

It will be remembered that when a fragment of the country, of such large dimensions as to divide a lode into two branches occurs, and these branches subsequently unite upon all sides, the

× 25
Fig. 35.—Veinstone, Huelgoët.

included rock is called a horse. Pieces of country rock in fragments too small to be distinguishable by the unassisted eye, are also frequently enclosed in siliceous veinstones. Fig. 35 represents a section of a veinstone of this class from a lode at Huelgoët, Finistère, France, seen under the microscope. It will be observed that the various disunited fragments of included slaty rock appear to have separated from one another very gradually, and the exact way in which they formerly fitted together is still readily traced. In this instance the fragments of slate are quite unaltered, and their outlines sharply defined. This, however, is not always the case, since in other specimens the enclosed fragments of country are often to a large extent replaced by silica, leaving only a shadowy image of their original forms.

The substitution, in rocks, of silica for other minerals is not unlike the replacement of woody fibre by the same substance in ordinary silicified woods, excepting that in the latter the silica is always more or less hydrated. Examples of this kind of silicification are often observable as capels where the walls of a vein have been subjected to silicifying action. When a mineral vein occurs in crystalline rocks, such as porphyry, thin sections not unfrequently show that portions of the country, now forming part of the veinstone, although to a large extent silicified, still exhibit traces of forms which were originally felspar crystals.

FIG. 36.—Fragment of lode, Knockmahon, Ireland; natural size.

a, Older veinstone with chalcopyrite; *b*, country rock.

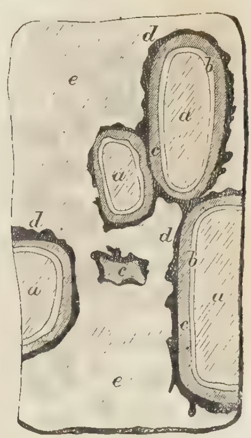


FIG. 37.—Fragment of lode, Bergmannstrost Mine, Clausthal; after v. Groddeck.

a, Older veinstone; *b*, quartz; *c*, galena; *d*, blende; *e*, calcite.

In *brecciated lodes*, as veins made up of broken materials are called, the included fragments, instead of having originally been pieces of the country rock, are in some instances portions of a previously existing metalliferous vein, which has been disrupted by the re-opening of the vein fissure, and its contents reduced to a fragmentary state by the subsequent grinding together of its walls.

In many cases a vein encloses at the same time pieces of the country rock and of veinstone belonging to an older lode; this is shown in Fig. 36, which represents a fragment from a quartzose copper lode at the Knockmahon Mines, Ireland.

In place of consisting simply of embedded fragments of older veinstone or of country rock, the inclusions in veins are sometimes covered by regular deposits of other minerals. When metallic sulphides or other ores have been thus deposited, they are known as *ring ores* or *cockade ores*.

Fig. 37 represents an example of the last-named formation from the Bergmannstrost Mine, Clausthal.

When the ores deposited around fragments of included rock have a radial crystalline structure, they are sometimes called *spherulitic ores*.

At Huelgoët the principal lead vein is in part composed of what would at first appear to be a conglomerate, consisting of quartz pebbles cemented together by blende, pyrites, quartz, and galena. On breaking these "pebbles" they are all found to consist of a central nucleus of slaty country rock, surrounded by an

FIG. 38.—"Pebble," Huelgoët; two-thirds natural size.
a, Line of fracture.

envelope of slightly chalcedonic quartz, and only in outward appearance differing from an ordinary quartz pebble in being somewhat less smooth.

Fig. 38 represents one of these pebbles which has been cut through and polished by the lapidary, and which in addition to a nucleus of dark slate, shows evidence, at *a*, that it has been broken by the movement of the enclosing walls and subsequently re-cemented by a growth of quartz.

The various minerals of which the filling of a vein fissure is made up, are frequently arranged as a succession of plates parallel to its walls. These plates or *combs* are aggregations of crystalline minerals, the separate crystals of which are usually arranged with their longer axes at right angles to the walls of the lode; while their form is more perfectly developed at the ends turned towards its centre than at the other extremity. The ribbon-like structure of *comby lodes* indicates long-continued chemical action, occasionally interrupted, but again renewed under different conditions; the substances deposited on the walls varying with the nature of the minerals held in solution at the time the bands were severally formed. Some parts of a vein may exhibit a comby structure, while others show no trace of any particular arrangement. Prošepny has proposed the word "crustification" to describe this layer-like arrangement.

Vein fissures occasionally present appearances of having again opened after having become filled with mineral, the new opening thus formed affording the requisite space for a further deposition of veinstone. In some cases the re-opening of the cavity appears to have been repeated several times in succession, the thickness of each comb indicating the width or progressive widening of the

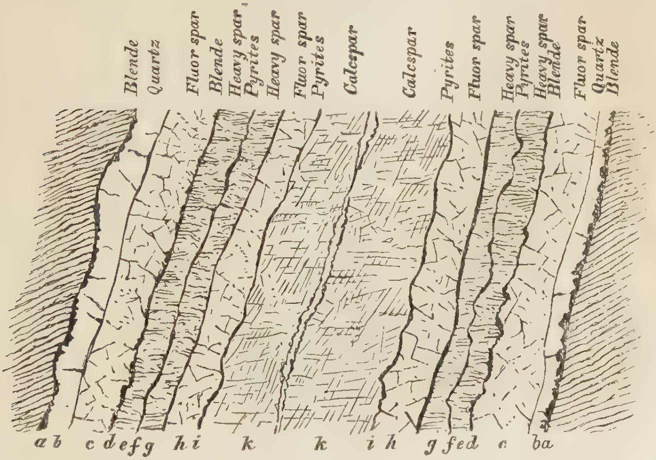


FIG. 39.—Section of the Drei Prinzen Spat Vein, near Freiberg; after v. Weissenbach.

fissure during the time its filling was being deposited. It not unfrequently happens that the re-opening of a fissure has been attended by a grinding together of the walls, resulting in the production of slickensides and flucans. In some lodes the width of the fissure would appear either to have gradually increased or to have remained unaltered during the whole period of its being filled, while successive deposits took place in such a way as to produce a series of bands arranged parallel to one another.

One of the most remarkable examples of symmetrical repetition in a comby lode is presented by the Drei Prinzen Spat Vein, near Freiberg, a portion of which is represented in Fig. 39. Next to the walls on each side is a crystallised deposit of blende followed by layers of quartz, succeeded by others of fluor spar, iron pyrites, and heavy spar, &c., as indicated in the figure; each comb on one side having one exactly corresponding to it on the other. The middle portion is occupied by crystals of calcite on either side of a central cavity, the whole showing ten symmetrical repetitions of six different minerals.

Such perfect symmetry is not, however, common, and when it occurs it does not afford convincing evidence that no re-opening of the fissure has taken place, since one might evidently be

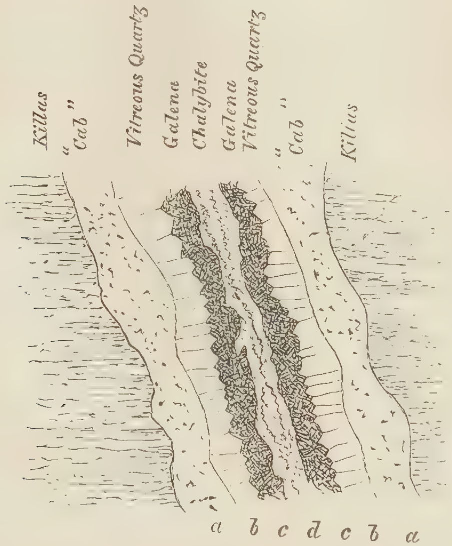


FIG. 40.—Section of vein at Huel Mary Ann; after Le Neve Foster.

produced without any perceptible displacement or grinding of the walls.

The combs of the same vein may be symmetrically arranged in one portion of its section, and occur without any degree of symmetry in another.

Fig. 40 represents a transverse section of part of a vein at Huel Mary Ann, near Liskeard, Cornwall, which furnishes an example of a lode in which the layers, which are not numerous, appear to be arranged symmetrically.[1] Here there are, first of all, two walls of killas or clay slate, and then, proceeding from the

[1] C. Le Neve Foster, "On the Lode at Huel Mary Ann, Menheniot," *Trans. Royal Geol. Soc. of Cornwall*, ix. 1875, p. 152.

walls inwards, a layer of chalcedonic quartz, *a*, locally called *cab*. To this follows a layer of vitreous crystallised quartz *b*, next galena *c*, and finally chalybite *d*.

Fig. 41 is a section of the same vein at a short distance from the foregoing, where it has a partly combed structure and partly a brecciated one. On the hanging wall the cab, *a*, is traversed by a vein of vitreous quartz, *b*, which crystallises out in a large vugh; then follows another band of quartz, *c*, while on the foot-wall there is a breccia, *d*, composed of fragments of killas and cab cemented together by galena and calcite. In this case the various phenomena

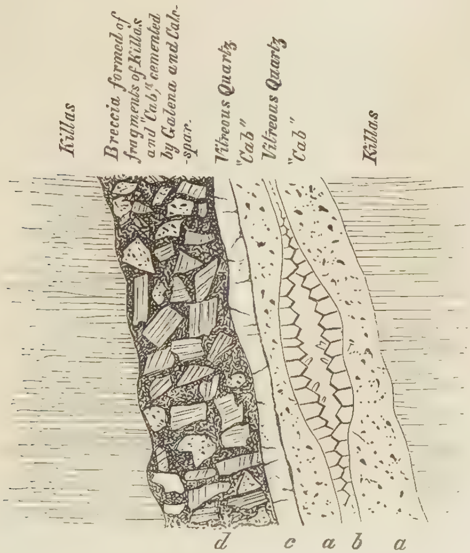


FIG. 41.—Section of vein at Huel Mary Ann; after Le Neve Foster.

connected with the formation of the lode probably occurred in the following sequence:—

Firstly, formation of the fissure, accompanied by a shifting of the strata. A succession of empty spaces were left, and some parts were more or less filled by fragments which had fallen from the walls. As might be anticipated, this breccia chiefly occurs on the foot-wall.

Secondly, deposition of the cab, which, to a certain extent, filled the fissure and cemented together the fragments from the walls.

Thirdly, re-opening of the fissure; the new line of fracture sometimes traversing the middle of the filling of cab, at others cutting across it, and ultimately following one of the walls of the original fissure. Pieces of the wall and of the previously-formed cab then fell in, and quartz, galena, chalybite, and calcite were successively deposited in the open spaces.

Fig. 42 is a section of a lode in granite at Carn Marth, near Redruth, one-twelfth natural size, affording a good example of a fissure which has been several times re-opened.[1] It will be observed that each re-opening has been attended by an amount

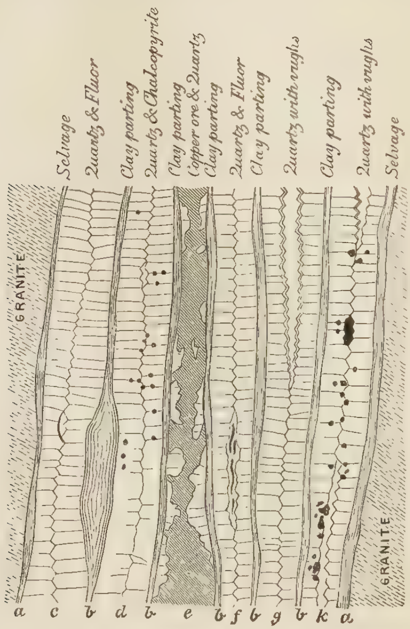


FIG. 42.—Section of vein, Carn Marth.

of grinding action between the walls, sufficient to produce a clay parting of considerable thickness. This lode is enclosed in granite, and the dots and patches of black in the figure represent spots and bunches of copper ore. It is right to add that the theory of successive openings in such cases as the present one has been seriously impugned by several recent writers on these subjects.

The arrangement of the various minerals in the combs of a vein is precisely that which would result from their crystallisation

[1] J. H. Collins, "On the Mining District of Cornwall and West Devon," *Institute of Mechanical Engineers, Proceedings*, 1873, p. 89.

either from solution or by sublimation; the successive layers are produced by deposits parallel to the walls, while the crystals have their longer axis directed towards the centre of the vein. It would therefore appear that the phenomena observed might be produced in at least two different ways, but this subject will be again referred to when we consider the various theories which have been advanced to account for the formation of mineral veins.

Distribution of the Ores in Lodes.—In a vast majority of cases the more metalliferous parts of a lode, or those which yield the ore sought in an approximately marketable state, constitute but a comparatively small proportion of the whole, and but few metalliferous veins are sufficiently rich throughout their extent to pay for the removal of the whole of the veinstone. A large proportion of the lode is consequently left standing in the mine, while the richer portions only are taken away and brought to the surface. It is always a matter of considerable uncertainty whether rich deposits of ore may or may not occur in a vein, and no definite opinion can be formed on the subject until a careful study has been made both of the vein and of the neighbourhood in which it is situated. In regions in which parallel lodes, similarly situated, have been extensively worked, the miner profits by the experience thus acquired, and considers there is a probability that like conditions may produce similar results. When, therefore, such lodes exist in any given locality and the position and direction of any courses of ore in one or more of them have been ascertained, there is a probability that the others may contain similar deposits.

It would be of great scientific interest, as well as of the utmost practical importance, if the causes of this unequal distribution of ore could be discovered, and some rule laid down for detecting the position of the richer portions of a lode. Unfortunately, up to the present time, no certain method of doing this has been found, and it is only by a careful study of the district in which a vein is situated that anything like an approximation to this knowledge can be acquired. The conclusion arrived at will be much influenced by numerous almost undefinable facts and indications, which, although they enable the miner who is well acquainted with a district to direct his operations with a considerable amount of accuracy, would probably lead him to the commission of grave mistakes if applied in a different locality. Miners with fixed ideas, resulting from observations made in a limited area, are consequently liable to make serious mistakes when they attempt to apply their experience in distant and totally new localities.

When a mass of ore extends in a lode in the direction of its course, horizontally, in such a way that a gallery or level driven through it for a distance of many fathoms is continuously or almost continuously in rich mineral, and this ore is again met with in levels above and below it, the deposit is known as a *course of ore*. Such courses of ore are sometimes very extensive, as, for example, in the adjoining mines of Huel Seton and Huel Crofty, in Cornwall, where a course of copper ore extended continuously over a length of 225 fathoms, and had an average depth of about fifty fathoms.

In the mining districts of the West of England when a course of ore is spoken of without specifying the metal that is present,

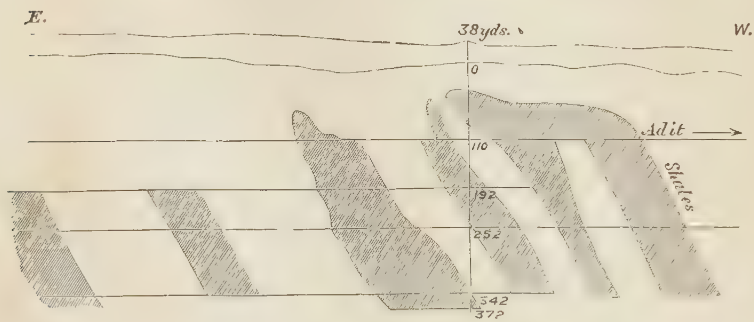


FIG. 43.—Longitudinal section of a portion of the Snailbeach Mine, Shropshire.

the word *copper* is often understood. Thus it is usual to speak of a course of ore, a course of tin, a course of lead, &c. Large masses of ore occurring in the mines of the new world are sometimes called *bonanzas*, but this term is chiefly restricted to deposits containing one of the precious metals.

When deposits of metalliferous minerals assume the form of bands or columns more or less steeply inclined in the plane of a lode, they are known as *shoots* (written often *chutes* in America) *of ore* or *chimneys of ore*. The shaded portions in Fig. 43 represent the mode of occurrence of galena at the celebrated Snailbeach Mine, Shropshire, which affords a good example of an ore occurring in shoots. The horizontal extent of a shoot of ore is for the most part somewhat limited, while its persistency in depth is often very considerable. As a general rule, all the ore-shoots in a given vein dip in the same direction, which, most commonly, is also that of the bedding, or cleavage, of the rocks through which the lode passes. The distinction between a course of ore and a shoot, although usually sufficiently definite, is nevertheless, to some extent, vague, since, in extreme cases, the form and character of a mass of ore may represent a sort of passage from the one form to the other. The term, course of ore, may, however, be regarded, generally, as applied to tabular, more or less horizontal masses of ore of unusual extent and richness, while the word shoot, which conveys the idea of a workable deposit, is chiefly used as indicating the high inclination and persistency in depth of the ore-bearing portions of a vein.

When a course or shoot of a metalliferous mineral has been discovered in any one of a series of parallel lodes traversing the same country rocks, there is a considerable probability that somewhat similar deposits may be met with in approximately corresponding positions in the other lodes of the group. Inasmuch as

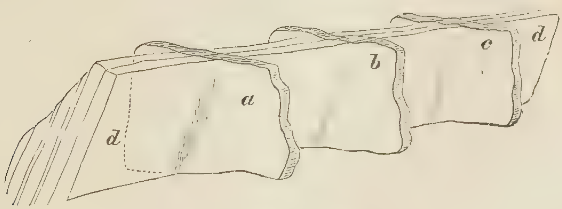


FIG. 44.—Ore deposits in parallel lodes.

the more valuable deposits found in a series of parallel lodes are usually enclosed in the same country rock, it follows that these, as well as the lodes themselves, will be approximately parallel; hence the aphorism of the miner, *ore against ore.*

This arrangement of the metalliferous contents of a series of veins will be understood on referring to Fig. 44, in which *a*, *b*, *c*, are veins, and *d* the country rock; the deposits of ore being indicated by lines of shading.

When the ore in a lode occurs in detached patches it is said to be *bunchy*, and each separate patch is called a *bunch.* Although, according to this definition, it may be sometimes difficult to distinguish between a small course of ore and a large bunch, the terms are usually well understood and are regarded as being fairly definite. It has been observed that in *bunchy lodes*, the bunches, like shoots of ore, have a tendency to arrange themselves in accordance with the dip, or cleavage, of the enclosing rocks.

In many cases the ores in a lode occur neither in courses, shoots, nor bunches, but are disseminated in a crystalline or granular form throughout the veinstone. Lodes in which the ores thus occur are, by Cornish miners, known as *dradge lodes.*

The conditions under which deposits of ore occur in mineral veins vary in different districts, and it would be impossible to lay down anything beyond very general rules relative to this subject. Attention will, however, be directed to these local peculiarities when the various districts in which they occur are specially described.

It may, however, be stated, speaking generally, that those lodes are most productive whose dips approach most nearly to the perpendicular, and that the most productive portions of lodes are usually enclosed between walls possessing a moderate degree of hardness. This may, to some extent, be accounted for by the fact that accumulations of débris from the wall rock will less frequently take place in the fissures of nearly vertical lodes than in those of which the inclination approximates more nearly to the horizontal. It will be obvious also that a larger number of fragments will fall into a vein fissure from a soft splintery hanging wall than from a moderately hard and sound one. A change in either the direction or inclination of a lode is frequently accompanied by a local enrichment at or near the angle ; it is also often observed that when a vein pinches the narrow part is richer than the wider portions.

Miners are aware that in all metalliferous districts lodes following certain known directions are more frequently productive than those which vary only a few degrees from that course. This may, perhaps, be accounted for on the assumption that fissures formed during periods when salts of various metals were held in solution by waters circulating through them, will become charged with ores of those metals. Fissures opened at subsequent periods will, in their turn, become filled with ores of metals resulting from the salts at that time circulating in solution, and which differ from, and have replaced those present during the period the first system of vein fissures was being filled. On the other hand, fissures may be formed at an epoch during which the circulating waters contained no metallic salts, and in that case the resulting veins will be non-metalliferous.

M. Moissenet, who has studied the metalliferous veins of different mining districts, and especially those of Cornwall, with reference to the relations existing between their productiveness and their direction, has endeavoured to explain the observed phenomena in accordance with M. Élie de Beaumont's theory of the *Réseau pentagonal.* The assumption of the simultaneous elevation of parallel mountain chains is however not generally received by geologists, and the conclusions arrived at by M. Moissenet are not always in accordance with established facts.

Outcrop of Lodes.—The outcrops and upper portions of metalliferous veins are often found to have undergone a series of chemical changes by which they have ultimately become transformed, more or less completely, into siliceous peroxide of iron and hydrated ferric oxide. This product of decomposition receives various names in different mining regions. By the Cornish miner it is called *gossan;* in France it is known as *chapeau de fer,* and in Germany as *eiserner Hut.* The *pacos* or *colorados* of South America are essentially similar productions, which, like all vein-cappings, vary to some extent in colour and composition.

The ferric oxide in these outcrops is most frequently derived from the oxidation of metallic sulphides containing a large proportion of iron, such as ordinary iron pyrites, magnetic pyrites, chalcopyrite, &c., and being disseminated generally throughout the mass, it imparts to it its usual predominating red or brown colour. In some cases the ferruginous capping of lodes is a result of the decomposition and peroxidation either of siderite, or of bitter spar containing iron.

Gossans often extend to a depth of many fathoms, but are seldom found much below the drainage level of the district. They sometimes contain valuable metals, such as gold, silver, copper and lead, which were originally associated with the minerals from which the ferric oxide was derived. The gold is invariably found in the metallic state; while the other metals may occur in combination with oxygen, chlorine, iodine, bromine, &c., or with carbonic, sulphuric, or phosphoric acids. Arsenic is also one of the metals often present in ferruginous outcrops, and native copper or silver is not of unfrequent occurrence. With increasing depth these products of decomposition gradually pass over either into sulphides, or into spathic ores, &c. In the same way the auriferous pyrites occurring near the outcrop of gold veins ordinarily becomes transformed into pulverulent oxide of iron, from which gold is readily separated either by washing or amalgamation. From this cause many auriferous quartz veins have, when worked near the surface, been found to readily yield their gold, but after the water-level has been reached, sulphides have made their appearance, and much difficulty has been experienced in treating the auriferous rock.

The same is the case with many other metals; thus a vein carrying sulphide of silver will have a gossan containing native silver and chloride of silver, both of which are readily amalgamable without special difficulty. A "free milling" silver ore will accordingly change in depth to an ore that has to be treated by more complicated methods, such as smelting or wet processes. Sulphides of lead and copper yield gossans containing these metals in an oxidised condition and therefore reducible by simple smelting with carbonaceous material. A marked example of the assistance that the superficial oxidation of certain ores gives to the miner is found in the Broken Hill Silver Mines of New South Wales. The shallow-lying ore was composed of highly argentiferous carbonate, &c., of lead comparatively free from zinc, which had doubtless been oxidised and leached out as a soluble sulphate, whilst the unoxidised ore in depth consists of an intimate mixture of galena and zinc blende that presents very great difficulties in its treatment—difficulties which have at this date (1896) not been entirely overcome.

In gossans of veins of the precious metals, a concentration of the valuable ingredient has almost always taken place. As the surface of the country was gradually lowered by denudation, the vein itself was simultaneously worn down and weathered away; the gold and silver contents of the vein however, owing to their great weight and to the insolubility of the first named in the metallic state, and of the second, whether as metal or as chloride, gradually accumulated in the gossanous portions of the vein immediately below the parts that were in process of destruction. The valuable contents of the vein have thus become concentrated in the upper part or the gossan, which therefore contains not only what may be called its normal tenour, but has also been enriched by an additional amount that properly belonged to those portions of the vein that had been destroyed and carried away. As a marked example of this, though every gold-field shows the same phenomenon, the Witwatersrand gold district may be cited, many of the "reefs" on which gave pannings up to many hundreds of ounces, and even showed crushings that for some time averaged six ounces to the ton, whilst in depth the average richness is pretty uniformly about 15 dwt. In Western Australia, some mines, like Bailey's Reward, yielded 15 ounces to the ton at the outcrop, and only as many pennyweights at 380 feet depth. Some of the argentiferous copper mines of Butte, Montana, were first started as silver mines; the silver remained as chloride in the gossan, whilst from a depth of 400 feet the copper had been leached out in a soluble form and concentrated lower down in the vein, producing a zone of secondary ore about 200 feet deep which contains about thrice its normal copper contents.[1]

These phenomena of gossan enrichment are often lost sight of in estimating the probable value of a lode; it must not be forgotten that the amount of such enrichment can never be determined from *à priori* considerations, and that it is unsafe to predicate anything about the average value of a vein until the undecomposed ore below water level has been cut. Cases have been known of rich gossans capping deposits too poor to be workable in depth.

The presence of such products of decomposition at the outcrop, has however, at all times and in all countries, been regarded by miners as affording an indication that a vein may, in depth, prove abundantly metalliferous.[2] It must, nevertheless, be borne in mind that the decomposition of common pyrites, and of various other ferriferous minerals, gives rise to the formation of a gossan differing from that which results from the oxidation of chalcopyrite chiefly in being somewhat more compact. The occurrence of gossan may consequently be regarded as indicating the probable presence of a metallic sulphide, and where one metallic sulphide is present in large quantities, others will probably be found.

When the ferruginous capping of a lode contains, as is often the case, other metals in addition to iron, their presence may be regarded as adding considerably to the probability of the occurrence of their ores at a greater depth. The wall rocks on either side of gossan outcrops are usually much decomposed and softened by the action upon them of the various solutions resulting from chemical changes which have taken place within the vein.

Grouping and Sequence of Minerals in Lodes.—Among the various substances constituting the filling of vein fissures, certain minerals are more frequently associated with one another than they are with others. In this way pyrites and chalcopyrite, blende and galena, wolfram and cassiterite, heavy spar and fluor spar, &c., are found together. These combinations, which are sometimes very complicated, are not always consistent, and as the number of minerals which occur in veins is extremely large, it

[1] J. Douglas, "The Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.* xix. 1890, p. 693.

[2] "A mine is ne'er so good as that
Which goes beneath an iron hat."
Old German Proverb.

would be very difficult to enumerate all the different combinations of this kind which have been observed. Definite associations of ores and veinstones are sometimes called *ore formations, vein formations, vein types,* &c. The grouping together of certain mineral species in metalliferous veins may possibly be due to the common solubility of these ores in the same medium, and to their ability to deposit crystals from the same solutions under similar conditions. Although it would be difficult to enumerate all the known associations of metalliferous ores in lodes, the following table will afford a general idea of the more simple groupings which they affect :—[1]

Association of Ores in Metalliferous Veins.

Two Members.	Three Members.	Four or more Members.
Galena, blende.	Galena, blende, iron pyrites. (Silver ores.)	Galena, blende, iron pyrites, quartz, *and* spathic iron ore, diallogite, brown spar, calc spar; *or* heavy spar.
Iron pyrites, chalcopyrite.	Iron pyrites, chalcopyrite, quartz. (Copper ores.)	Iron pyrites, chalcopyrite, galena, blende, *and* spathic iron ore, diallogite, brown spar, calc spar; *or* heavy spar.
Gold, quartz.	Gold, quartz, iron pyrites.	Gold, quartz, iron pyrites, galena, blende, arsenical pyrites; *and* spathic iron ore, diallogite, brown spar, calc spar.
Cobalt and nickel ores.	Cobalt and nickel ores, and iron pyrites.	Cobalt and nickel ores, iron pyrites; *and* galena, blende, quartz, spathic iron ore, diallogite, brown spar, calc spar; *or* heavy spar.
Tin ore, wolfram.	Tin ore, wolfram, quartz.	Tin ore, wolfram, quartz, mica, tourmaline, topaz, &c.
Gold, tellurium.	Gold, tellurium, tetrahedrite (Various tellurium ores.)	Gold, tellurium, tetrahedrite, quartz; *and* brown spar; *or* calc spar.
Cinnabar, tetrahedrite.	Cinnabar, tetrahedrite, pyrites. (Various ores of quicksilver.)	Cinnabar, tetrahedrite, pyrites, quartz; *and* spathic iron ore, diallogite, brown spar, calc spar; *or* heavy spar.
Magnetite, chlorite.	Magnetite, chlorite, garnet.	Magnetite, chlorite, garnet, pyroxene, hornblende, pyrites, &c.

[1] Bernhard v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd edition, Freiberg, 1859, p. 37. American Translation, 1870, p. 14.

The succession of the various minerals constituting either a series of dissimilar combs, or the successive crystallisations of geodes or druses, has long attracted the attention of the scientific miner. Many years ago v. Weissenbach observed the following sequence of vein-material from the wall rock to the centre in the system of lodes which occur in the district around Brand, a few miles west of Freiberg.[1]

1. Quartz veins containing iron pyrites, black blende and galena, with mispickel, affording a moderate proportion of silver.

2. Diallogite and brown spar, in addition to the above-mentioned ores, which are rich in silver and contain patches of argentiferous tetrahedrite, and other rich silver ores.

3. Spathose iron ore, fluor spar, and heavy spar, over which a grayish variety of brown spar has sometimes been deposited. The ores of group 2 are present, but in less quantities, and the galena disseminated through the heavy spar contains but little silver.

4. Calcite, occasionally enclosing rich silver ores, but without the ores of group 1.

The sequence of the various minerals constituting metalliferous veins has also been examined by both Breithaupt and Henwood, neither of whom was enabled to deduce from his observations any general law of succession. With comparatively few exceptions, however, all the various series of minerals in veinstones begin with a layer of quartz, but beyond this it is found that, even in the same district, the different minerals constituting subsequent deposits frequently vary, not only in the order of their succession, but also in their composition. Fluor spar and, to a lesser extent, barytes are conspicuously absent from the gangue of auriferous veins.

It is noteworthy that gold, which is constantly associated with cubical iron pyrites, is scarcely ever found accompanying marcasite.[2] Perhaps some recent experiments of A. P. Brown,[3] who finds that the iron in the former mineral is in the ferrous and in the latter in the ferric state, may account for this, if it be supposed that the iron has passed into the higher state of combination as a consequence of reducing gold salts from their solutions.

The following table has been constructed from a much longer

[1] C. G. A. v. Weissenbach, *Abbildungen merkwürdiger Gangverhältnisse aus dem sächsischen Erzgebirge*, Leipzig, 1836, p. 31.

[2] H. Louis, "On the Mode of Occurrence of Gold," *Min. Mag.* xx. 1893, No. 47, p. 241.

[3] *Proc. Amer. Philos. Soc.* 1894, xxxiii. p. 225.

one by W. J. Henwood, in which he summarises the results of his personal observations relating to the order of succession of the minerals in various lodes in Cornwall.[1]

POSITIONS OF CONSTITUENT MINERALS IN CERTAIN LODES IN CORNWALL.

Rock.	Substance next adjoining the rock.	Substance next to that which adjoins the rock.	Minerals adjoining that in the last column.	Minerals adjoining that in the last column.	Localities.
Granite.	Quartz.	Quartz.	Chalcedony.	......	Pedn-an-drea.
	,,	,,	Arseniate of iron.	......	Huel Gorland.
	,,	,,	Wolfram.	......	St. Michael's Mount
	,,	,,	Uranite.	......	Gunnis Lake.
	,,	Oxide of tin.	Tungstate of lime	......	Huel Friendship.
	Earthy brown iron ore.	Vitreous copper ore.	Earthy black copper ore.	......	Huel Jewel.
Greenstone.	Quartz.	Stalactitic quartz.	Quartz.	......	Huel Edward.
	,,	Quartz.	Aragonite.	......	Levant.
	,,	,,	Hydrous oxide of iron.	......	Restormel.
	,,	Chlorite.	Oxide of tin.	......	Huel Vor.
	,,	Arsenical pyrites.	Arsenical pyrites.	......	Huel Unity Wood.
	,,	Chlorite.	Copper pyrites.	Mineral pitch.	North Roskear.
Clay slate.	Quartz.	Quartz.	Copper pyrites.	Quartz.	East Crinnis.
	,,	,,	Copper pyrites.	Copper pyrites.	United Hills.
	,,	Iron pyrites.	Carbonate of iron.	Spathose iron ore.	Virtuous Lady
	,,	Galena.	Galena.	Quartz.	Huel Rose.
	,,	Copper pyrites.	Sulphide of bismuth.	......	Fowey Consols.
	,,	Quartz.	Blende.	Fluor spar.	Polberrow.
Elvan.	Oxide of tin.	Oxide of tin.	......	......	Wherry Mine.
	Quartz.	Earthy brown iron ore.	Blue carbonate of copper.	......	Ting Tang.
	Earthy brown iron ore.	Native copper.	......	......	Huel Buller.
	Quartz.	Vitreous copper ore.	......	......	Ting Tang.
	,,	Red oxide of copper.	......	......	,,
	,,	Chrysocolla.	......	......	,,

Among the most important investigations relative to this subject are those published by Sandberger on the paragenesis of the minerals constituting the veins at Schapbach, in Baden. In this mine two distinct lode formations are developed on the course of the Friedrich-Christian Vein where it traverses the gneiss namely the Schapbachite, or bismuth-silver-ore formation, represented by the so-called "Hard Branch," and the coarse-copper and lead-ore-bearing fluor-spar-pyrites formation.

The succession of the different minerals contained in both these formations has been carefully worked out, and numerous sec tios across the veins at different points are given. A comprehensive

[1] *Trans. Royal Geol. Soc. of Cornwall*, v. 1843, Table C, facing p. 214.

table is also furnished showing the sequence of the various *secondary* minerals resulting from the decomposition of the *primary* or normal ores, &c., originally deposited in the vein fissure. In this case, as in those already quoted, there is great irregularity with regard to the succession of the various deposits, but in order to render this obvious it will be sufficient to give the results of Sandberger's examination of the Hard Branch only:

FRIEDRICH-CHRISTIAN VEIN.—PARAGENESIS OF HARD BRANCH.[1]

a. 1. Decomposed granular banded gneiss, with reddish felspar and whitish mica.
2. White quartz, passing into grayish hornstone and milk-blue chalcedony, with angular fragments of the country rock, disseminated Schapbachite, galena (I), and copper pyrites (I).
3. Quartz ∞R. $\pm$ R.
4. Galena ∞O∞. O (Twining on O). Native bismuth $-$2R.0R, in very small crystals in the rarely-occurring druses.

b. 1. Gneiss (as above).
2. Compact quartz and chalcedony, with strings of Schapbachite an inch wide, and nests of massive copper pyrites (I) and crystals of iron pyrites $\left(\frac{\infty O2}{2} \cdot \infty O \infty\right)$.
3. Roselite in translucent blebs in fissures, coating quartz and iron pyrites.

c. 1. Gray hornstone with disseminated Schapbachite and galena (I), copper pyrites (I), and iron pyrites (I).
2. White quartz ($\infty \pm$ R), galena (I), (∞O∞.O).
Native bismuth (0R. $-$ 2R), bismuth glance occurring only in druses, in aggregates of very small acicular crystals.

d. 1. Whitish gneiss.
2. Gray quartz with Schapbachite and galena (I), and copper pyrites (I)
3. White quartz, with numerous impressions of cubes of fluor spar.
4. White quartz in crystals (∞R. $\pm$ R).

e. 1. Whitish gneiss.
2. Gray quartz, with Schapbachite and galena.
3. Coarse foliated calc spar (I), crystallised in large scalenohedra (R^3) in druses, but mostly corroded and earthy or dull.

f. 1. Whitish gneiss.
2. White compact quartz.
3. Fluor spar (I) pale green, mixed with calc spar (I) and coarse-grained galena.

g. 1. Quartz (II) in larger crystals, with galena.
2. White calc spar (I) (R^3).
3. Quartz (IV) and copper pyrites (III) in thin crusts.

h. 1. Quartz (II) in larger crystals, with milk-white roundish enclosures.
2. Copper pyrites (II) in twins.
3. Brown spar (R).
4. Calc spar (II) (∞R. R^3. $-\frac{1}{2}$R.R).

[1] Fridolin Sandberger, *Untersuchungen über Erzgänge,* Part I. p. 86, Wiesbaden, 1882.

i. 1. Quartz (II) in larger crystals.
2. Calc spar, in sheaf-like aggregates of scalenohedra (R^3) an inch long, superficially altered into chalybite, encrusted and penetrated by
3. Quartz (III) pseudomorphous after barytes.
4. Calc spar (II) in small groups of crystals ($\infty R. - \frac{1}{2}R$).
5. Copper pyrites (III) crystallised, with small crystalline aggregates of quartz (IV).

k. 1. Compact quartz with angular fragments of gneiss, and disseminated galena and copper pyrites (I).
2. Fluor spar in rough yellowish cubes, in regular intergrowths with quartz (III) after barytes.
3. Calc spar (II) ($\infty R. R^3. - \frac{1}{2}R$).
4. Copper pyrites (III) crystallised.

In the foregoing table, when a mineral has been formed at only one period in the history of the lode, no large numeral is affixed. The numbers I, II, III, and IV, indicate four successive stages of deposition for each mineral, but they do not refer to any particular band or contemporaneously formed pair of bands in the lode. These latter are indicated by the small numerals arranged under the different sections *a*, *b*, *c*, &c., in the table of paragenesis. The sections show the contents of the lode at certain spots, selected as typical of the differences occurring successively along its course.

The various minerals of which metalliferous veins are composed do not always, even in the same lode, occur in a similar order of succession, and when the same minerals are found in corresponding order in different veins, it by no means follows that they are of equal geological age. Metalliferous minerals occur in veins of every age, and the same minerals are sometimes found in a similar order of succession in those belonging to very different periods; such series being not unfrequently repeated more than once in the same vein. In such cases, similar processes of formation appear to have been periodically repeated.

These successions of mineral deposits cannot therefore be regarded as characteristic of particular geological periods, neither must their nature be considered as dependent on their age. The same periods have not everywhere produced similar combinations or successions, and different periods totally dissimilar ones; consequently, it is not possible from the nature of the mineral combinations and successions which occur in a given vein to determine its geological age. In the case of vein fissures formed at different periods, the mineral deposits which take place will depend upon the nature of the substances dissolved in the waters circulating through them at the time of their formation. In the same locality the nature of these solutions has changed from time to time, while similar solutions have re-appeared at certain intervals which have no known general connection with geological time. These changes have been confined to comparatively limited areas, and are not believed to have affected all veins of the same age.

In addition to the minerals originally deposited in vein fissures during the progress of filling, lodes often contain other mineral substances which have been derived from these original deposits by their decomposition and a new arrangement of their constituents. Secondary formations of this kind, for the most part, constitute a very small proportion only of a lode, and occur chiefly near its outcrop and in the vicinity of its intersection by other veins. In this way, in addition to oxide of iron derived from the decomposition of sulphides, the gossans forming the outcrops and shallower portions of many lodes frequently contain massicot, cerussite, anglesite, pyromorphite, wulfenite, &c., resulting from the alteration of galena; and cuprite, melaconite, malachite, azurite, &c., from the decomposition of chalcopyrite.

The formation of these secondary minerals can however be generally traced to well-known chemical reactions, and is therefore quite distinct from the agencies by which the deposition of the original vein material was accomplished.

The occurrence in lodes of minerals exhibiting pseudomorphic forms, produced by their deposition in moulds left by the removal of crystals of other substances, and the presence, in drusy cavities, of stalactites of calcite, quartz, pyrites, &c., indicate that a partial decomposition and re-arrangement of some of their constituents has been effected by the action of water at comparatively low temperatures.

The water now issuing from the back of one of the cross-cuts at Dolcoath deposits in considerable quantities a soft, grayish-brown precipitate, *iron sinter*, which frequently assumes stalactitic forms. Similar incrustations, although generally less abundant, are found in nearly all deep mines wherever water issues from the vicinity of a vein and flows over the surface of the adjacent rock.

Two analyses made of air-dried specimens of this substance afforded the results given on the following page.

No. I. is an analysis of this deposit made in my (J. A. P.) laboratory; No. II. is that of another specimen, made by Mr. Dugald Campbell.

	I.	II.
Water combined	12·77	11·45
Water hygroscopic	15·90	15·20
Ferric oxide	36·30	37·75
Manganic oxide	trace	trace
Arsenic acid	32·47	32·55
Arsenious acid	trace	0·68
Sulphuric acid	2·65	2·52
	100·09	100·15

Influence of Depth upon Lodes.—For a long time there appears to have been an impression that lodes are productive to a certain depth only, and that all below is barren and without value. The earlier miners in California were so fully impressed with the idea that the outcrops were more productive than the deeper portions of the same veins that when the quartz ceased to afford remunerative results, they seldom proceeded to any considerable additional depth before suspending their operations. Within the last thirty years, however, experience has entirely changed their opinion upon this subject, as deeper workings have led to the conclusion that there is no evidence tending to indicate a progressive falling off in the yield of gold, once the region of surface enrichment, which has already been fully discussed, has been passed through.

Auriferous veins are always variable in their yield, and it may be assumed that those which at the surface afforded evidence of the presence of gold first claimed the attention of the miner. These, after having been worked to a more or less considerable depth, ultimately became unproductive, and although further prosecution of the operations might have led to fresh discoveries, the miner, who was usually without capital, soon transferred his operations to some other outcrop showing visible gold.

Another reason for the prevalence of this belief among the earlier miners may be traced to the fact, which has been previously mentioned, that gold is almost invariably associated with iron pyrites and other metallic sulphides, and these becoming decomposed, near the surface, liberate the gold, which is readily collected by washing and amalgamation. In the deeper portions of a vein, these sulphides remain undecomposed, and although an equal amount of gold may be present, the results obtained by the miner are less satisfactory. With improved machinery and better methods of treatment, this difficulty has now to a very great extent disappeared, and though it is well known that the gold liberated by the natural decomposition of pyrites can be very easily extracted by direct amalgamation, some authorities have recently gone so far as to declare that, when worked on a very large scale, pyritic ores can be treated quite as cheaply as free milling ones.

The working of mines is more easily and more cheaply conducted near the surface than at more considerable depths, and as the difficulty and cost increase with the progress downwards, horizontal explorations on the strike are, in the aggregate, much more extensive than are those upon the dip of lodes. When at a given depth a lode or shoot of ore has temporarily ceased to be productive, it frequently happens that any additional sinking would necessitate the erection of more powerful machinery, and hence there is a greater tendency to drive levels than to sink shafts. Statements relative to the entire disappearance of lodes in depth must therefore be received with caution, since, had the workings been continued, the vein would probably have again been found and have again become productive. Comparatively few mines have reached four hundred fathoms, but there is reason to believe that true veins extend to depths to which the miner will be unable to follow them.

According to Lieber, many lodes both in North and South Carolina appear to contain gold near the surface, while lower down they yield lead and copper ores with but little gold. The succession from the top downwards is stated to be gold, lead, copper; but his observations were not made in each case on the same lode, and the conclusions at which he arrives are at variance with those of other observers. Messrs. Shepard and Eights state that gold is present in these veins at all depths that have as yet been reached, but is easily recognisable in those parts only where the decomposition of sulphides has resulted in the formation of gossan and the liberation of gold. My own (J. A. P.) examination of the region in question would lead me to agree with the last named observers.

Many of the lodes in Cornwall which in the shallower levels yielded an abundance of copper ores, now at greater depths afford large quantities of tin oxide; but whether copper ores again occur still deeper is unknown. If it were established that changes in the composition of lodes took place at approximately fixed depths from the original surface, the phenomena might be regarded as due to the constantly increasing temperature and pressure resulting from greater depth; but up to the present time we are without any reliable data bearing upon this subject.

Influences of the Country Rock.—Every one who has written upon the mining districts of Cornwall, has remarked that almost the whole of the mineral wealth of that county occurs within a distance of some two or three miles on each side of the junction of granite and clay slate or killas. According to W. J. Henwood, who carefully studied the subject, no part of this line appears, however, to have been notably more productive than any other part of the same extent within the distance mentioned.[1] And although lodes not uncommonly run for many fathoms with granite on one side and slate on the other, or with either of these rocks forming one wall and elvan, *quartz-porphyry*, the opposite one; yet the portions of the lodes thus contained between dissimilar rocks have not generally been found to be the most productive. The metalliferous contents of lodes appear also to be not only affected by the mineral composition of the contiguous rocks, but in some degree also by their position and mechanical structure.

Whether the rocks be granite, slate, or elvan, their hardest portions are always quartzose, and in these the lodes are seldom rich. In granite, a fine-grained rock, locally known as *whetstone*, is always an unfavourable indication, while if that which is of a coarser texture contains large white and sharply-defined crystals of felspar, the indication is equally unfavourable.

If, on the contrary, the grain of the rock be neither very fine, on the one hand, nor particularly coarse on the other, while the enclosed crystals of felspar have a greenish, brownish, or pinkish tint, with indistinct outlines merging into the ground-mass, quartz, mica, and sometimes schorl being present, the character of the rock is considered to be a favourable one, and lodes enclosed in it may be expected to be fairly productive, especially of tin ore.

A hard, fine-grained quartzose elvan that contains schorl, either diffused as a colouring matter only, or in groups of radiating crystals, is not a favourable country rock, as the lodes in such elvans frequently divide and split up into innumerable branches, which reunite when they approach softer and more felspathic varieties of the same rock. The varieties of elvan most favourable to riches differ slightly as regards tin and copper ores. Lodes are sometimes tolerably productive of the former, even when split into strings and enclosed in a glassy quartzose elvan. In the case of copper ores, on the contrary,

[1] *Trans. Roy. Geo. Soc. of Cornwall*, v. 1843, pp. 219–225.

unless the rock be soft, and to some extent decomposed, the lodes dwindle and become unprofitable.

In the neighbourhood of the St. Just and St. Ives copper mines, the rock is a fine-grained hornblendic slate containing felspar. A decomposed slaty rock of a pale grayish hue passing into a dull white, and sometimes marked between the laminæ with bluish spots, accompanies the richer portions of the copper lodes in the greater part of the Gwennap district. The same or very similar rocks occur in the neighbourhood of St. Agnes, in some portions of the St. Austell district, and in the neighbourhood of Callington. In these tin ore is by no means abundant, although it is found in the shallower parts of some of the lodes. Copper ores not only occur in this rock, but have been plentiful in the same lodes after leaving it and entering a dark-blue quartzose slate. In far the greater number of instances, however, the riches dwindle or suddenly disappear with this change of the country rock. In some parts of the Gwennap district, a slate of a reddish colour is regarded as being equally unfavourable to the yield of the lodes by which it may be intersected.

In many of the most productive mines of Western and Central Cornwall, and generally throughout the Tavistock district, copper ores, chiefly occurring as copper pyrites, are found in a deep-blue clay slate having a glassy or silky lustre, and opening in thick horizontal joints which coincide with the planes of cleavage. Lodes in this rock do not usually contain tin ore, and if the slate assumes a deeper hue, the copper ores are replaced by iron pyrites; while if the rock becomes quartzose, even the iron pyrites itself disappears.

Wherever tin ore is abundant, the slate is of a tolerably uniform character, being deep-blue in colour with occasionally a somewhat greenish tinge, and a gloss of silkiness on the surface of the cleavage planes. A diminution in the depth of colour, and a softening in the texture of the rock, are considered unfavourable indications. The lodes which afford lead ore occur in bluish or grayish slates, and are generally situated at considerable distances from the granite.

With regard to the mechanical structure of rocks. it has been observed that, when in granite, slate, or even in elvan, the joints nearly parallel to the course of a lode fall towards it in descending, it may be regarded as a favourable indication. On the other hand, when such joints diverge from the lode as they go downwards, it is generally considered to be an indication of poverty. Many joints traversing a lode appear to exercise an unfavourable influence upon it, and a course of ore is sometimes cut completely off by a joint running across the lode. In slates, whenever they become quartzose, their cleavage planes are almost invariably much curved or contorted, and the rock is more than ordinarily fissile; such conditions are generally considered unfavourable to the presence of large deposits of ore. When, on the contrary, the planes of cleavage are not distinctly curved, and the rock exhibits a thickly lamellar structure, the lodes passing through it may be expected to be fairly productive. All these indications are, however, extremely local and often confined within very narrow limits, since in the same rock there is frequently an alteration of the lodes as soon as the character of the surrounding country becomes slightly modified.

In the north of England, where the lead veins are situated in regions of Carboniferous Limestone, a singular dependence is observed between the contents of a vein and the nature of the country rock. In Cumberland, the veins divide limestones, sandstones, and shales, and these are brought into various opposition to one another by the displacements which accompany nearly all the veins. A vein is sometimes productive of lead ore under all circumstances of opposition in the enclosing rocks. When limestone forms the walls, its productiveness is usually at the maximum, and schist, and solid sandstones, likewise enclose productive veins; but they are generally contracted in width and impoverished in their contents whenever they are included between walls of slate, and even when one wall only is occupied by that rock the same effect is frequently observed.

In Derbyshire, the veins pass through the Mountain Limestone, and often through its associated igneous rocks, as well as across the various accumulations of shales and sandstones. The lead ore generally, but not always, occurs in the limestone series and most abundantly in the upper portions of it. The igneous rocks, *toadstones* (*todt* German dead, or unproductive), are sometimes dense, hard traps, while at others, though originally vesicular, the vesicles may be now filled by various infiltrated minerals; they are generally regarded as unfavourable to the productiveness of the enclosed veins. The Derbyshire miners were formerly of opinion that veins do not traverse these toadstones or *blackstones*, as they are sometimes locally termed, but it is now well known that the true fissure veins, or *rakes*, pass through these igneous rocks as well as through the limestones, but that where the *former* constitute the walls of the vein, lead ore is usually absent.

Among the limestones themselves, certain beds are considered more favourable than others as walls to lead veins, and the presence of dolomite is always regarded as an unfavourable indication. Although lead veins are frequently continued through certain shales overlying the limestones, which sometimes contain a considerable amount of carbonaceous matter, veins so enclosed are seldom productive. Many of the smaller metalliferous veins in the Derbyshire limestones are, in point of fact, merely joints in the rock which have received a deposit of lead ore of sufficient importance to induce the miner to follow them in his workings. In Alston Moor, Teesdale, Weardale, and Swaledale the upper thick limestone or Great Limestone is far the richest in lead ore.

In the district around Freiberg the lodes producing silver ores are generally enclosed in gneiss. This rock, which is divided into many different varieties, is traversed by dykes of porphyry and greenstone, and passes into mica schists containing beds of limestone, but v. Cotta states that the miners attach little importance to any of these variations of the country rock. The gneiss of the Erzgebirge may be divided into two principal varieties, namely, the common *gray gneiss*, and the *red gneiss*, so called because its felspar has a red colour. Both the gray and the red gneiss vary considerably in composition and texture, and it sometimes becomes difficult to determine whether a particular modification should be classified with the gray gneiss or with the red. The typical red gneiss would appear to present all the characteristics of an igneous rock, which is never the case with the normal gray gneiss of the Freiberg district. The gray gneiss contains from 64 to 67 per cent. of silica, and is composed of orthoclase, a small proportion of oligoclase with quartz, and much dark-coloured mica. The red gneiss contains from 74 to 76 per cent. of silica, and consists of orthoclase, quartz, and a little nearly colourless mica. According to v. Cotta and Müller, throughout the Erzgebirge the gray gneiss appears to exercise a more favourable influence on the metalliferous contents of the lode than the red gneiss, which contains comparatively few metalliferous veins.[1] It, however, appears that there are numerous intermediate grades between the two extremes which cannot with certainty be assigned to either variety. Müller's generalisations must con-

[1] B. v. Cotta and H. Müller, *Gangstudien*, i. 1850, p. 209.

sequently lose much of both their practical and scientific importance.

At Kongsberg, in Norway, the mines are situated in gneiss and crystalline schists, of which the district for a length of about a hundred miles and a width of some fifty miles is chiefly composed. Certain belts or zones of these crystalline rocks, known as *fahlbands*, are of considerable length and breadth, and are impregnated with finely divided sulphides of iron, copper, and zinc, with sometimes also those of lead, cobalt, and silver. The iron pyrites is often to some extent decomposed, giving rise to the formation of hydrated ferric oxide, which is locally regarded as an indication of the presence of silver ores. In the Kongsberg district there are several of these fahlbands, parallel in strike and inclination with the other gneissoid and schistose rocks of which they form a member. These fahlbands are themselves traversed by metalliferous veins containing silver and other ores, which are never productive except where they intersect a fahlband. In this instance it would appear that the impregnation of the veins with metalliferous minerals is directly dependent on the nature of the enclosing rock, rendering it probable that the metalliferous minerals were originally derived from the fahlbands, from which their removal and subsequent concentration in lodes have been effected by chemical agencies. Quite similar phenomena are exhibited by the *indicators* of Ballarat, as will be more particularly pointed out hereafter (see p. 637).

The foregoing and many similar examples of the influences exercised by country rocks upon the lodes passing through them have been long known as isolated facts, but the investigations of Sandberger and others have thrown much additional light upon the subject, and have invested it with a significance which it did not previously possess. The results of these investigations will be stated, and their bearing upon the productiveness of lodes discussed, when we consider the various theories which have been advanced to account for the formation of metalliferous veins.

Palæontology of Mineral Veins.—Mr. Charles Moore, who paid much attention to this subject, found that many of the clays or flucans associated with the lead lodes in Carboniferous Limestone enclose numerous fossils of Carboniferous, Permian, Rhætic, and Liassic age. He, moreover, entertained the opinion that veins of this class are of purely marine origin, and that the various organisms which they contain were deposited in open fissures existing in the sea bottoms of the several periods to which the fossils severally belong.[1]

It would appear however far more reasonable to suppose that, in the majority of cases, the various organisms which have from time to time been discovered in veins had already become fossilized when they were transported by the agency of water from higher ground into the various fissures of the limestone. The investigations of Mr. Moore comprehended the examination of materials derived from veins and vein fissures in the Carboniferous Limestones of Wharfedale, Wensleydale, Weardale, Teesdale, Swaledale, Alston Moor, Keswick, North and South Wales, and parts of Somersetshire.

In the Carboniferous Limestone districts of Holwell and Frome, Rhœtic and Liassic organisms form a large proportion of the fossils present in the veins, and the same is the case throughout the Mendip range and in South Wales. In North Wales and in the north of England, on the contrary, Carboniferous remains are most frequent, while those of later age are exceptions, some of these being Entomostraca of Permian species. According to Mr. Moore, fossil remains are of more frequent occurrence in veins traversing the Carboniferous Limestones of the Mendip Hills than they are in those of any other locality which he examined; but, with one exception, he never failed to find fossils wherever he sought for them in veins enclosed in limestones belonging to this formation.

Age of Mineral Veins.—True veins or lodes must in all cases necessarily be of more recent origin than the rocks in which they are enclosed, and when one vein crosses another it evidently must have been formed subsequently to the vein so intersected. In this way the relative ages of different veins occurring in a given district may often be determined without much difficulty, but to assign the formation of any vein or group of veins to a definite period of geological time is frequently more difficult. Sometimes also it is not easy to determine whether or not lodes are older than certain neighbouring rocks which have not been intersected by them. When, however, a vein does not traverse the stratum immediately above it, or is cut off in direction by a band of rock which it nowhere penetrates; or, again, if a given rock contains fragments of a neighbouring vein, it becomes evident that the vein may in each case be regarded as being older than the rock.

[1] *Report of the British Association for the Advancement of Science for* 1869, p. 360.

In this way it can often be shown that a vein must be older than certain formations in its neighbourhood, although it will generally be more difficult to determine how much older the vein may be than the evidently more recent rock. Such a determination can only be accomplished when the filling of a vein fissure may be referred to a period which elapsed between the formation of the rock which it traverses and that of a later deposit of well ascertained age, following closely in geological succession. Metalliferous veins are, as a rule, of more frequent occurrence in the older rocks than in the more recent ones, and from this circumstance it might possibly be inferred that the formation of lodes is a process which has gradually decreased in activity with the progress of time. It, however, appears far more probable that the formation of lodes has taken place at all periods of the world's history, and that, as a consequence, they are more frequently enclosed in the older rocks than in the newer ones; which, from being of less age, have been subjected during a less extended period to vein-producing influences. The following may be quoted as examples of mineral veins of comparatively recent date. In the department of Aveyron, in France, lodes of argentiferous galena associated with ores of copper traverse the Lias. In Algeria, lodes of the same class are enclosed in rocks belonging to the Cretaceous period. In California, a proportion of the auriferous veins are included in rocks of Jurassic age, while the auriferous quartz veins of Vöröspatak, in Transylvania, traverse Tertiary sandstones.

Further evidence that quartz veins are sometimes of very recent origin is afforded by the fact that in the vicinity of Volcano, in Amador County, California, a distinctly marked quartz vein is observed to cut through beds of sand and gravel, and presents unmistakable evidence of having been formed subsequently to their deposition, by the action of water holding silica in solution. This vein is chiefly composed of chalcedony and agate, but portions of it are more or less stained by a ferruginous deposit. This is by no means a solitary case, many other localities having been noticed where quartz veins, almost identical in their general features with those met with in the auriferous slates, must have been formed during the most recent geological epochs.[1]

From certain phenomena which have been observed in California, it would appear probable that in various localities lodes and

[1] *Geological Survey of California*, i. 1865, p. 276.

other metalliferous deposits may, even at the present time, be in active progress of formation.

One of the largest deposits of sulphur in California occurs in Lake County, a mile beyond the ridge which bounds Borax Lake on its north-eastern side, and is many acres in extent. This "Sulphur Bank" is composed of a much decomposed volcanic rock, traversed by numerous fissures, from which gases, steam and water, either in the form of spray or of vapour, constantly issue; and throughout the entire mass sulphur has been deposited in such large quantities that, at a short distance, the whole appears to consist of that substance. In the immediate neighbourhood of this solfatara are springs which give off carbonic acid, and of which the waters contain carbonates of sodium and ammonium, chloride of sodium, borax, &c.

The sulphur from this locality contains a small amount of mercury in the form of cinnabar, and the sides of the fissures in the volcanic rocks through which the gases and water make their escape are sometimes coated with gelatinous silica, beneath which is a layer of chalcedony resting upon a stratum of crystalline quartz. This siliceous deposit contains pyrites and a notable percentage of cinnabar, or is stained by a tarry hydrocarbon; while the crystals of quartz enclose liquid cavities in which the usual bubbles are distinctly visible.

In the year 1866 I (J. A. P.) visited Borax Lake and the neighbouring Sulphur Bank in company with Mr. R. Oxland, who was the first to call attention to the presence of cinnabar in the sulphur from this locality; and in 1868 I published a paper calling attention to the probability of certain mineral deposits having been the result of hydrothermal or solfataric action.[1]

For some years this solfatara was worked as a source of sulphur only; but during these operations so large an amount of cinnabar was discovered, both in the decomposed basaltic rock and in the sedimentary strata beneath it, as ultimately to lead to the opening up of the Sulphur Bank as a mercury mine. This has yielded large quantities of quicksilver, and affords a striking and instructive example of a recently formed mineral deposit resulting from agencies apparently still in operation.

Many years ago, silver was found in the sinter-like deposit from a hot spring in the county of Colusa; and previous to 1865, Professor Whitney had been shown at Clear Lake some peculiar and

[1] J. A. Phillips, "Notes on the Chemical Geology of the Gold-fields of California," *Phil. Mag.*, xxxvi. 1868, p. 321.

interesting specimens of water-worn cinnabar enclosing specks of gold, said to have been found near Sulphur Springs in the same county.[1]

These, from being water-worn, and from not having been found *in situ*, necessarily lost a certain portion of the interest which would have otherwise been attached to them. Mr. Melville Attwood, of Saucelito, has however furnished me with a specimen of cinnabar from Colusa County, which, after having been formed upon one of the surfaces of a fissure, had subsequently become covered by a brilliant deposit of metallic gold.

Steamboat Springs, in the State of Nevada, are situated near the base of a volcanic hill seven miles, in a direct line, north-west of Virginia City and of the famous silver mines on the Great Comstock Lode. The rock at this place is traversed by several parallel fissures, which either give issue to heated waters or simply throw off clouds of steam. The most active group of these crevices comprehends five parallel longitudinal openings extending, nearly in a straight line, for a distance of about a thousand yards; their general direction is nearly north-east and south-west, and all of them are included within a zone two hundred yards in width. They are sometimes filled with boiling water which overflows in the form of a rivulet, while at other times violent ebullition is heard to be taking place at a short distance below the surface.

These fissures are lined with a siliceous incrustation, which is being constantly deposited, while a central longitudinal opening allows of the escape of gases, steam and boiling water. The water is slightly alkaline, and contains carbonate of sodium, sulphate of sodium, common salt, &c. Carbonic acid escapes nearly along the whole line, while sulphuretted hydrogen is evolved and a small quantity of sulphur deposited at certain points. The fissures, which appear to have been subjected to a series of repeated widenings, such as would result from an unequal movement of their walls, are lined, sometimes to a thickness of several feet, by incrustations of silica of various degrees of hydration, containing hydrated ferric oxide and, exceptionally, crystals of iron pyrites. This silica exhibits the ribbon-like structure so frequently observed in mineral veins, and, when examined under the microscope, is seen to consist of alternately amorphous and crystalline bands, enclosing druses lined with minute crystals of quartz.

[1] *Geological Survey of California*, i. 1865, p. 92.

At a distance of nearly a mile, in a westerly direction, from the locality above described is an older group of fissures in every respect similar to those of Steamboat Springs, except that they are no longer traversed by hot water, although still at various points giving off a little steam and carbonic acid. Towards the southern extremity of the principal fissure of this group the siliceous deposit extends considerably beyond the edges of the cleft, and has accumulated to a distance of many yards on each side of the opening. The silica of this deposit is sometimes chalcedonic and contains nodules of hyalite; the larger proportion of it, however, although somewhat friable, is distinctly crystalline. The crystals contain numerous liquid cavities, and exhibit the usual optical and other characteristics of ordinary quartz. Besides oxides of iron and manganese, this quartz contains small quantities of iron and copper pyrites; and in a paper on the Gold Regions of California, published in 1863, M. Laur states that he had found it to contain distinct traces of gold. With regard to these deposits, this gentleman remarks that, so far as auriferous quartz veins are concerned, Steamboat Springs appear to place before us a sort of practical verification of the theory which regards a certain class of metalliferous deposits as being produced by mineral waters in the fissures through which they circulate.[1]

For a long time local attention does not appear to have been directed to the Steamboat Valley; but in the year 1878 one of the older fissures was opened by a tunnel to a depth of fifty feet from the surface, and the veinstone was there found so impregnated with cinnabar as to yield a mercurial ore of some commercial value. At this depth the temperature was not sufficiently high to cause inconvenience to the workmen, and five samples of the ore which were subjected to assay gave an average yield of 2·90 per cent. of mercury. Steamboat Springs thus afford another example of the recent formation of a metalliferous deposit by the agency of heated waters.

In continuation of this subject it may be mentioned that a deposit of bright-red cinnabar in a brecciated vein mass occurs near the hot springs at Calistoga, at the foot of Mount St. Helena. Here fragments of an amorphous siliceous rock are cemented together by crystallised quartz showing distinct lines of accretion, throughout which minute granules of sulphide of mercury are plentifully disseminated.

The Great Comstock Lode is situated in a volcanic district

[1] *Annales des Mines*, iii. 1863, p. 423.

seven miles south-east of Steamboat Springs, has a nearly similar orientation, and is enclosed between walls either of diabase, or of diorite on one side and diabase on the other. This vein, of which the gangue is chiefly siliceous, although calcite is also sometimes present, was first attacked by the miner in the year 1859, and since that time has yielded enormous amounts of silver and gold.

The temperature of the waters issuing from mines worked upon the Comstock Lode has always been high, but it was not until they had attained a considerable depth below the surface that the workmen first became inconvenienced by extraordinary heat. At their present greatest depth (above 3,000 feet) water issues from the rock at a temperature of 157° Fahr. (70° C.); and according to Mr. John A. Church, who has published valuable observations on the heat of the Comstock Mines, at least 4,200,000 tons of water are annually pumped from the workings at a minimum temperature of 135° Fahr.[1] He also estimates that to elevate such a large volume of water from the mean temperature of the atmosphere to that which it attains in the mines, would require 47,700 tons of coal. In addition to this, however, 7,859 tons of coal would, he calculates, be required to supply the heat absorbed by the air which passes along the various shafts and galleries through which it is diverted for the purposes of ventilation. It follows, therefore, that to develop the total amount of heat necessary to raise the water and air circulating in these mines from the mean temperature of the atmosphere to that which they respectively attain, 55,560 tons of coal, or 97,700 cords of firewood, would be annually required.

Mr. Church, in his paper, quotes four different analyses of waters from the Comstock Lode taken at different depths. These, as might have been anticipated, vary somewhat as to the relative proportions of the various substances present; but they contain on an average 42·62 grains of solid matter to the gallon. Of this amount, 20·74 grains are sulphate of calcium, 12·13 grains carbonate of potassium, 4·85 grains carbonate of sodium, and 0·66 grain chloride of sodium. In order to ascertain, approximately, to what extent the production of the large amount of heat absorbed by the water may be ascribed to oxidation of sulphur and iron, Mr. Church first calculates the quantity which would be developed by the oxidation of pyrites equivalent to the calcic sulphate in

[1] "The Heat of the Comstock Mines," *Trans. Amer. Institute of Min. Eng.*, vii. 1879, p. 45. "The Comstock Lode; its Formation and History," New York, 1879, p. 189.

solution. Having found that this amounts to only $\frac{1}{143}$ part of that required, he subsequently seeks another solution for the difficulty, and, without bringing forward any calculations in support of the hypothesis, attributes this enormous development of heat to the kaolinisation of felspar in the adjacent rocks.

This view, however new and ingenious, is unfortunately purely speculative, and in the present state of our knowledge geologists, generally, will regard this phenomenon as a last trace of volcanic activity. Mr. Church adduces the high temperature of the waters of Steamboat Springs as a proof that the rocks of this region are capable, by the kaolinisation of felspar, of producing sufficient heat to raise large quantities of water to the boiling-point; but these springs give rise to an evolution of sulphuretted hydrogen, and, occasionally, to a deposition of sulphur, which cannot be results of the decomposition of felspar. It is probable that the Comstock Lode and the hot springs in the Steamboat Valley have had a somewhat similar origin, but, in the case of the former, volcanic agencies are no longer so actively in operation, while both sulphur and sinter, if originally present, have been removed by denudation. There can be no doubt that fissures and cavities have sometimes been filled by infiltration from the enclosing rocks, as well as by percolation from the surface. The operation of these agencies is perhaps, in most instances, extremely slow, although according to R. Brough Smyth, even gold, under certain conditions, may be deposited in appreciable quantities within comparatively short periods. This author states that, in the gold-fields of Victoria, pieces of highly mineralised fossil wood, taken from the deeper workings, as well as timber used for supporting galleries, which had remained in the mine for some years, have exhibited, under the microscope, particles of gold adhering to and intermixed with crystals of iron pyrites, all through the central parts of the wood.[1] This is confirmed by Mr. Ulrich, who says that in the gold-drifts pyrites is often found incrusting or replacing roots and driftwood, and that samples, assayed by Messrs. Daintree, Latta, and Newberry, have yielded amounts of gold varying from a few pennyweights to several ounces per ton. According to Mr. H. A. Thompson, a specimen of pyrites from the centre of an old tree-trunk gave by assay above 30 oz. of gold per ton.[2]

Genesis of Mineral Veins.—The origin of metalliferous veins is

[1] *The Gold-fields and Mineral Districts of Victoria*, Melbourne, 1869, p. 74.

[2] Alfred R. C. Selwyn and George H. F. Ulrich, *Notes on the Physical Geography, Geology, and Mineralogy of Victoria*, Melbourne, 1866, p. 56.

a subject which has long occupied the attention of geologists, and various theories have, at different times, been framed with the object of explaining the causes which have led to their formation.

Little is said upon this subject by Greek and Latin authors when referring to mines and minerals. Diodorus Siculus, however, who lived and wrote during the first years of the Christian era, states that the mountains of Spain are traversed by metalliferous veins.

Pliny, whose death is supposed to have taken place A.D. 79, tells us in the thirty-third Book of his Natural History that gold is found in mountainous districts, and that veins producing it traverse the rocks in different directions, and often appear in the walls or sides of wells. He further informs us that if a lead vein be allowed to remain for some time unworked, air being at the same time freely admitted into the mine, a fresh growth of lead ore will take place and the lode will become even richer than before.

Werner, in his *New Theory of the Origin of Veins*, has given a concise history of the older views on this subject, of which a brief summary may not be without interest.[1]

Georgius Agricola, whose real name was Bauer, and who was born in 1494 at Glauchau in the Saxon Erzgebirge, treats of the position and crossing of lodes in the twenty-fourth chapter of his *Bermannus*, and at still greater length in his great work *De Re Metallica* (1556). In the third chapter of the third book of his work *De Ortu et Causis Subterraneorum* (1546), Agricola treats of the formation of veins. He supposes the fissures in which they are found to have been formed partly at the same time as the enclosing rocks, and partly afterwards by the waters which penetrated into them. With respect to the clays and stones constituting portions of metalliferous veins, he conceives the former to have resulted from the abrasion of neighbouring rocks, and to have been carried into the vein fissures by water; the latter he regards as resulting from the clayey or earthy matters which have become hardened partly by the effects of heat and cold, and partly by a "lapidific juice." Minerals and metals he regards as being deposited from solution in water, and he considers the then prevalent belief that lodes are of the same age as the globe itself "an opinion of the vulgar."

Rössler, who died in 1673, also regarded veins as fissures previously existing in the rock and subsequently filled with minerals.[2]

[1] A. G. Werner, *Neue Theorie von der Entstehung der Gänge*, Freiberg, 1791. An English translation of this book by Charles Anderson, M.D., was published at Edinburgh in 1809.

[2] B. Rössler, *Speculum metallurgiæ politissimum, oder hellpolierter Bergbauspiegel*, Dresden, 1700.

Becher (1669) ascribes the formation of metals and minerals to subterranean vapours penetrating the veins and producing a peculiar change in their earthy and stony constituents.[1]

Henckel (1725) attributes the formation of the contents of veins to a peculiar exhalation produced and engendered by a "fermentation" supposed to take place in the interior of rocks.[2]

Hoffman (1738) supposes lodes to have been formed in the fissures of rocks, but speaks of this as being an hypothesis only.[3]

Zimmerman (1746) considers veins and the minerals of which they are composed, to have been produced by a transformation of the substance of the enclosing rocks; this alteration being assisted by certain saline substances which prepare and render the earthy matters capable of being changed into metalliferous minerals and their accompanying veinstones.[4]

Von Oppel (1749), formerly Captain-General of the mines of Saxony, admits without reservation that veins were formerly fissures in the rock which were afterwards filled with mineral substances of a different nature from the surrounding rock.[5]

Lehmann (1753) is of opinion that veins are fissures which have been filled by nature with stones, minerals, metals, and clay, and that they appear to be the branches and shoots of an immense trunk placed at a prodigious depth in the bowels of the earth. From this central workshop where nature carries on the manufacture of the metals, the metalliferous constituents of lodes have issued in the form of "vapours and exhalations." [6]

Delius (1770) considers vein fissures to be rents, which have been since filled up, caused by the drying of the rocks. He is, moreover, of opinion that rain, having penetrated the substance of the country rocks, has dissolved or suspended, and afterwards carried into the rents, the different materials which have served as a base for the formation of the gangue and various associated ores.[7]

Baumer (1779) states that veins differ both in form and substance from the strata in which they occur. Their formation he considers to be posterior to that of the rock traversed by them, and they appear to have been formed under the sea, as they are often covered

[1] J. J. Becher, *Physica Subterranea*, Frankfurt, 1669.

[2] J. F. Henckel, *Pyritologia oder Kieshistorie*, Leipzig, 1725. An English translation of this work was published in London in 1757.

[3] J. G. Hoffman, *De Matricibus Metallorum*, Leipzig, 1738.

[4] C. F. Zimmerman, *Ober-Sächsische Bergakademie*, Dresden, 1746.

[5] v. Oppel, *Anleitung zur Markscheidekunst*, Dresden, 1749.

[6] J. G. Lehmann, *Abhandlung von den Metallmüttern*, Berlin, 1753.

[7] C. T. Delius, *Abhandlung von den Ursprüngen der Gebirge*, Leipzig, 1770.

by beds of schist, and marine animals are sometimes found in them in a fossil state.[1]

Gerhard (1781) believes vein fissures to have been produced at very different periods of time, and is disposed to think that "subterraneous fermentations" may have contributed to their formation. He supposes further that water penetrating the country rock dissolves certain substances, and afterwards passing into vein fissures, there deposits the minerals which it previously held in solution. These minerals, he is of opinion, existed originally in the adjacent rocks, and have been carried in a state of aqueous solution into the fissures, where they are now found in the form of metalliferous veins.[2]

Von Trebra (1785) does not appear to have possessed any very definite ideas on the subject of metalliferous veins, but ascribes their origin mainly to the action of "putrefaction and fermentation." He appears to regard the two terms as synonymous, and subsequently defines the latter as "the quality which, acting by insensible degrees, produces the most perfect transformation in the bowels of the earth." [3]

Lasius (1789) considers veins to have been formed in rents produced by revolutions of nature, and these he believes to have been afterwards filled with water containing carbonic acid, which thus acquired the property of dissolving various earthy and metallic matters contained in the rocks through which they percolated. These substances were afterwards precipitated by certain other bodies in the fissures in which they are now found. He, however, is not clear as to whether the metallic particles were already present in the substance of the rock, or were formed in them by the action of water upon minute "metallic seeds." [4]

Werner (1791), in his work on the formation of veins, propounds at considerable length his views upon this subject, and of these the following may be regarded as being a brief abstract. All true veins were originally open rents, which were afterwards filled with mineral matter from above.

Rents or fissures may have been produced by various causes. Mountains have been formed by a successive accumulation of different beds upon one another; the resulting mass was at first

[1] J. G. Baumer, *Fundamenta Geographiæ et Hydrographiæ subterraneæ*, Gotha, 1779.

[2] C. A. Gerhard, *Geschichte des Mineral-Reichs*, Berlin, 1781.

[3] F. W. H. v. Trebra, *Erfahrungen von Innern der Gebirge*, Dessau, 1785.

[4] G. O. S. Lasius, *Beobachtungen uber die Harzgebirge*, Hanover, 1789.

wet and possessed little solidity or coherence, so that when the accumulation had attained a certain height it yielded to its weight, sank, and cracked. In proportion as the waters which had previously assisted to support such an accumulation had partially retired, the masses, losing their previous support, yielded to the action of gravitation, and portions of the mountain thus became detached, falling to the "free side," where the least resistance was opposed. The cracking of a mountain mass by dessication, by earthquakes, or by other similar causes, may also have contributed to the formation of rents of this character.

The same precipitation which in the humid way formed the strata and beds of the rock also furnished the substance of mineral veins. This took place during the period when the solution, from which the precipitate was deposited, covered the already existing fissures, the upper portions of which were, as yet, open, and wholly or in part empty.

The various theories which have at different times been brought forward to account for the formation of metalliferous veins, admit of being classified as follows :—

1. Theory of Contemporaneous Formation.
2. " Igneous Injection.
3. " Electric Currents.
4. " Aqueous Deposition from above.
5. " Sublimation.
6. " Lateral Secretion.
7. " Ascension.

1. *Theory of Contemporaneous Formation.*—This theory supposes that mineral veins originated contemporaneously with the enclosing rock, and they are regarded as mere accidental phenomena governed by no fixed laws of formation. This hypothesis is at variance with all known facts relating to the subject, and may consequently be dismissed without further consideration.

2. *Theory of Igneous Injection.*—According to this theory, which is generally adopted with regard to dykes of igneous rocks, the constituents of metalliferous veins, under the influence of intense heat and pressure, and when in a more or less fluid state, have been ejected from below into cracks and fissures in the superincumbent strata. Examples of the occurrence of metalliferous matter disseminated through eruptive rocks are by no means uncommon, but this theory entirely fails to account for many of the commonest

and most characteristic phenomena which are observed in connection with mineral veins. The comby structure of lodes, and the changes which occur in their character when they pass from one series of rocks into another, are not only quite incapable of explanation by this theory; but, moreover, had veins been generally thus formed, a tendency would probably have been manifested by the heavier ores and metals to arrange themselves in the lowest portions of the lodes in which they occur.

In some of the limestone coals of the north of England, small veins of galena, sometimes almost pure, sometimes containing in addition calcite, barytes, and more rarely iron pyrites and quartz, occur actually traversing the coal seams. Fig. 45 is a cross

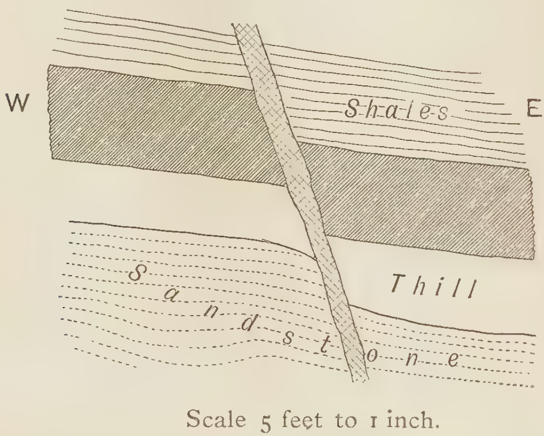


FIG. 45.—Section of lead vein in Shilbottle Colliery.

section of such an occurrence at Shilbottle Colliery in Northumberland, where a vein of lead ore is found filling a narrow fissure which is accompanied by a small fault. In the coal itself the vein filling consists of galena and a little calcite, whilst in the underclay beneath the seam it carries chiefly calcite, quartz, and iron pyrites. The coal is bright, firm, and quite unaltered, unless perhaps rather more tender close to the lead vein of which it forms the walls. It is evident that if this vein had been formed by the injection of molten galena, the coal in contact with it must have been more or less coked or cindered, as commonly happens when a coal seam is intersected by an igneous dyke.

The veins of Lake Superior, which annually yield such large quantities of native copper, have been cited as affording examples of veins produced by igneous injection; but metallic copper is there found associated with metallic silver, whereas, had the veins been the result of igneous fusion, an alloy of the two metals would certainly have been formed.[1] In the same region crystals of pure silver deposited on the surface of masses of native copper are by no means of unfrequent occurrence. In these lodes, moreover, native copper is found enclosed in crystals of calcite and in other minerals, where it must evidently have been deposited, with the other constituents of the crystalline mass, from aqueous solution.

There is, however, distinct evidence that many igneous rocks contain, disseminated through them, minute quantities of various compounds of the heavy metals, and in some cases these may have been dissolved out and the metals again thrown down in such a way as to form valuable metalliferous deposits. The so-called *mullock veins* of Australia and elsewhere are examples of eruptive dykes which, having become decomposed, the originally disseminated gold and silver have, with quartz and other minerals, been deposited in the joints and fissures of the rock. There seems to be little doubt but that some deposits have been formed by segregation, either of large masses or of minute particles of metalliferous minerals, from igneous rocks.

Although unaltered dykes of this kind are not often, if ever, sufficiently rich to be classed with metalliferous deposits, it is by no means improbable that richer intrusions may exceptionally occur, and that some of the so-called eruptive lodes at Schemnitz and other localities may directly owe their origin to eruptive agencies.

3. *Theory of Electric Currents.*—Mr. R. W. Fox after having ascertained the existence of electric currents in many of the metalliferous veins of Cornwall, suggested the probability of this force having acted on various metallic chlorides and sulphides dissolved in the waters traversing vein fissures, in such a way as to determine the mode of the distribution of the ores therein. He also endeavoured to account for the prevalence of an easterly and westerly direction in the principal lodes of Cornwall by their position in relation to the earth's magnetism. A similar theory was put forward by John Leithart[2] in 1838 as the result of his observations in the Alston Moor district; he held that fissures were formed by electricity in a manner analogous to the produc-

[1] J. S. Newberry, "The Origin and Classification of Ore Deposits," *School of Mines Quarterly*, March, 1880, New York.

[2] *Practical Observations on Mineral Veins*, 1838.

tion of fractures by lightning and electrical discharges; that these fissures were filled partly by "transmutive" action on the walls of the fissure, and partly by the introduction of foreign matter, both effects being the result of electrical action; he quoted the fact that north and south veins in the Alston Moor district are less metalliferous than east and west veins as a proof of his theory. His electrical theories apart, there is much in his writings that seems to foreshadow some of the modern views respecting vein formation.

Weighty objections to these electrical theories have, however, been pointed out by W. J. Henwood and others, and observed facts appear to indicate that the general direction of veins differs so entirely in different mining districts that their course probably depends rather on lines of fracture, produced by plutonic, volcanic, or other agencies, than on the action of electric currents. Professor Reich, who repeated the experiments of Fox, also obtained a deflection of the magnetic needle when he connected two portions of the same lode by means of conducting wires. He, however, very clearly explains this as the effect of the contact of various ores composing isolated bunches, separated by sterile veinstone which acts as a moist conductor. By connecting points free from ore, Reich was unable to obtain the slightest deviation of the needle, and although the chemical changes which are continually taking place in exposed masses of ore give rise to electric currents, it by no means follows that the original distribution of the same ore was due to the agency of electricity.

4. *Theory of Aqueous Deposition from above.*—This was first advanced by Werner, who supposes the contents of mineral veins to have been deposited from metalliferous solutions which flowed from above into the fissures. If, however, fluids containing metalliferous substances at any period actually covered the surface, there would appear to be no reason why they should have deposited their contents in fissures rather than elsewhere. Besides which, if the deposition of vein matter took place in the way supposed, we might expect to find at least some portion of the veinstone stratified horizontally, which in true veins is never seen to be the case. Many conclusive reasons against the ideas promulgated by Werner might, if necessary, be brought forward, but his views with regard to the origin of veins have long ceased to carry the weight once attached to them, and are now very generally abandoned.

Mr. Wallace, in his work on *The Laws which Regulate the*

Deposition of Lead Ore in Veins,[1] which laws, although having special reference to the Alston Moor district, are advanced by him as explaining ore deposits in veins generally, appears to adopt to some extent the views of Werner with certain additions and modifications. He states that all the lead veins of that part of England are most productive where furthest removed from seats of plutonic action, the richest deposits being in the upper part of the Carboniferous Limestone where no igneous rocks are found, and that there is nothing in that district to support the theory that lead ore is due either to exhalations from below or to matter injected in a fluid state among the consolidated sedimentary rocks. On the contrary, he thinks a more probable cause of the deposits of lead ore in Alston Moor may be traced to segregations resulting from the decomposition of the wall rocks of the veins in which lead ore is found.

In adopting the doctrine of segregation, he proposes to combine it with another cause without which there would, he believes, be no important deposit of minerals, namely, that of recent atmospheric agencies. Without the passage of large bodies of water, derived from the rainfall of the district, from the surface downwards, and their free circulation in the veins, he maintains that the conditions would not be favourable to the deposition of minerals. He states also that in all cases such deposits are found only where fluids percolate freely from the surface and circulate through the veins, and that such conditions only occur in strata situated at moderate depths, and at a considerable distance from the surface watershed. He believes these agents, combined with electrical action, to have been the means of extracting the minerals from the neighbouring rocks, that this operation is still in progress, and that the filling of vein fissures has been entirely accomplished since the Glacial period.

The theory of aqueous deposition from above has still more recently been advocated by Professor Stewart, of Nevada, but Mr. J. S. Newberry, who has devoted a long time to the study of the ore deposits of the Western States of America, considers that this theory is not only not sustained, but, on the contrary, is disproved, by the statements brought forward.

5. *Theory of Sublimation.*—According to the theory of sublimation, vein fissures were filled by the volatilization of metalliferous minerals derived from the ignited interior of the globe.

[1] W. Wallace, *The Laws which Regulate the Deposition of Lead Ore in Veins; Illustrated by the Mining Districts of Alston Moor*, London, 1861.

Durocher[1] considers the unequal distribution of the ores in all lodes as strongly confirmatory of the hypothesis of their formation by this agency. He believes that ores can only have been so distributed by the action of currents of dissimilar gases or vapours circulating through the fissures in the veinstone. Of these he distinguishes two kinds, namely, metallic vapours, *émanations motrices,* and vapours of sulphur and other mineralisers, which he designates *émanations fixatrices.* These, when they circulate through different fissures without meeting, or through the same fissures at different periods, produce no result, but, when they meet together, give rise to various metalliferous deposits. Numerous experimenters have shown the possibility of producing by such means many of the ores which occur in metalliferous veins, and deposits of magnetite and specular iron ore produced by the decomposition of chlorides of iron by watery vapour in the fissures of volcanic rocks, afford well-known examples of the natural production of minerals by reactions of this class.

Plattner long ago observed the formation, by sublimation, of magnetite and galena in the Freiberg furnaces, and Daubrée[2] has succeeded by the aid of chlorine, fluorine, &c., in producing by sublimation tin oxide and oxide of titanium (*see also* page 146). Similar results were obtained by Durocher, who passed metallic vapours, &c., through heated glass tubes, and thus caused the formation of blende, pyrites, galena, and various other metallic sulphides.[3] Evidence in favour of the theory of sublimation has, by some geologists, been supposed to be furnished by the position of metalliferous particles found on the under sides of crystals lining the walls of certain lodes, as at Nagýag, in Transylvania, where metallic arsenic has been deposited on the lower faces only of crystals of diallogite.

Such phenomena are, however, of comparatively rare occurrence, and will in no way account for the existence of the earthy minerals which constitute the larger proportion of the filling of nearly all large veins. It is impossible also to account by this means, either for the variations which take place in the character of lodes on passing from one rock into another, or for many of the complicated phenomena exhibited by veins at their intersections with one another.

In the case of some irregular deposits where large masses have

[1] *Comptes rendus de l'Académie des Sciences*, xxviii. 1849, p. 607.

[2] *Comp. rend.*, xxix. 1849, p. 227.

[3] *Comp. rend.*, xxxii. 1851, p. 823; xlii. 1856, p. 850.

become impregnated by a metalliferous mineral, as especially exemplified in certain mercury mines, it is perhaps not improbable that the diffusion of the ore may have been partially effected by sublimation. The deposition of cinnabar, iron pyrites, and even gold, from the mingled steam and water of some of the geysers of California would indicate the possibility of such impregnations taking place, but, in the present state of our knowledge of the subject, it would appear improbable that the silica which usually forms so large a proportion of veinstones, and frequently occurs in combs of interlocking crystals, should have been deposited otherwise than from aqueous solution. It is therefore probable that, although sublimation may sometimes have contributed to the impregnation of rocks by cinnabar and other minerals, its action must have been of secondary importance in the formation of regular metalliferous veins.

This theory has recently been revived in a somewhat different form by Vogt,[1] at any rate as far as the formation of stanniferous deposits is concerned. Starting from the experiments and observations of Daubrée he looks upon tin deposits as having been produced by chemical changes caused by metallic vapours connected with igneous outbursts, so that the resulting ores might metasomatically replace other minerals and not be necessarily deposited in open fissures ; he uses the word *pneumatolysis* for this action.

6. *Theory of Lateral Secretion.*—This theory teaches that water percolating through the country rock has, by the aid of carbonic acid and other natural solvents, dissolved out of it all the materials now forming the constituents of mineral veins. Delius, Gerhard, and Lasius held that this explanation was that most in accordance with observed facts, and more recently Bischof endeavoured to found this hypothesis upon more scientific grounds. He, however, appears to have failed to seek for the constituents of the different ores, found in veins, in the surrounding rocks, but suggests the possibility of their being found there if sought for, at the same time remarking that the proof of this was nevertheless wanting.

About the year 1873, Professor Sandberger, of the University of Würzburg, began to direct his attention to a chemical examination of the relations existing between the mineralogical contents of mineral veins and the nature of the rocks which they traverse.

[1] J. H. L. Vogt, "Beiträge zur genetischen Classification der durch magmatische Differentiations-processe und der durch Pneumatolyse entstandenen Erzvorkommen," *Zeitsch f. Prakt. Geol.*, 1894, p. 381.

Although some of the more common heavy metals had previously been discovered in various crystalline and other rocks, this was the first systematic attempt to study the effects produced upon veins by the country rock through which they pass. For the purpose of this investigation the north-eastern portion of the Black Forest in the neighbourhood of Schapbach, Wittichen-Reinerzau, and Wolfach, was selected, this being a district with which the Professor had been long and intimately acquainted. The lodes in this region, although situated at short distances only from one another, exhibit very remarkable differences, which are most strongly marked on their passing from one description of rock into another; the same change, although in a less degree, however, is also noticeable on the passage of a lode from one variety of gneiss into another somewhat differing from it in character.

Quantitative analyses were carefully made of ores, veinstones, and country rocks, the latter being subjected to general analysis. These investigations resulted in the derivation of the veinstones from the country rock being clearly established, but the origin of the associated metalliferous minerals still remained without explanation. As, however, it became more and more evident that substances so constantly associated as ores and veinstones must have had a common origin, a new method of investigation was finally adopted. Instead of operating upon a large quantity of rock, and making a general analysis of it, as had been done by Forchhammer, the crystallised constituent silicates, such as olivine, augite, hornblende and mica, were carefully isolated and subjected to analysis, the quantity treated in each case being not less than ten grammes. In this way, with the exception of tellurium, gold, and mercury, which from want of the necessary appliances were not sought for, all the elements usually occurring in metalliferous veins were found in appreciable quantities.

The cause of the differences which occur in the contents of veins, which although near one another traverse different rocks, was also explained to the satisfaction of the investigator, who subsequently satisfied himself that the heavy metals occur in the silicates of crystalline rocks of every geological age.[1]

Sandberger has since extended his investigations over very considerable areas, and has thus been enabled to arrive at certain general and very important conclusions. In the case of olivine,

[1] Fridolin Sandberger, *Untersuchungen über Erzgänge*, Part I. p. 23.

augite, hornblende, or mica, from ten to twenty grammes will be found a sufficient amount for quantitative analysis. In olivine, iron, nickel, copper, and cobalt were constantly recognised, but the latter metal in very small quantities. The same may be said with regard to augites, especially those of the gabbros, diabases, melaphyres, augite-porphyries, augite-andesites, and basalts. Copper, cobalt and iron occur in the augite of these rocks in notable quantities, and nickel, lead, tin and zinc are also frequently present. Antimony and arsenic have hitherto been detected in certain localities only, but when present these metals are generally found in considerable quantity, as, for example, in the diabases of St. Andreasberg in the Harz, in which antimony is associated with lead. Hornblende from the older hornblendic rocks constantly contains copper, arsenic, and cobalt, and along with these very distinct indications of nickel. Hornblende from the more recent rocks contains the same metals, but in addition to them lead, antimony, and tin, with occasionally zinc and bismuth.

The largest number of hitherto undetected heavy metals is, however, found in micas, the researches on this group having been carried so far that they may now, to some extent, be classified in accordance with the preponderance of certain metallic elements. All lithia micas, even when derived from the most varied localities both in Europe and America, are stanniferous, and they usually also contain arsenic, copper, bismuth, and sometimes uranium. True muscovites are the micas poorest in heavy metals, although copper is seldom entirely absent. The black micas from the older gneiss of the Erzgebirge, contain arsenic, lead, zinc, and a little copper, and the same applies to those of the southern Black Forest, while the black mica from the Spessart contains copper, cobalt, nickel, and bismuth. Arsenic, lead, and zinc are found in the dark mica from the propylite of Schemnitz, and in the rubellan of Pölma, near the boundary of Saxony and Bohemia.

Attention is called by Sandberger to the fact that both baryta and lime are present in various felspars as well as in the minerals with which they are associated, and that fluorine occurs in many micas. The decomposition of such minerals will therefore yield the materials for the formation of many varieties of veinstone, while the liberated silica will be deposited in the form of quartz.

Organic matter is sometimes present in considerable quantities in metalliferous veins, not only in the form of carbonic acid, but also as graphite and anthracite, as at Schneeberg and elsewhere.

It also occurs as the colouring matter of fluor spar and of smoky quartz. This, it is argued by the supporters of the theory of lateral secretion, will be found whenever the amount originally present has been more than sufficient to transform the metallic sulphates into sulphides, &c.

Lodes however occur not only in crystalline rocks, but also in semi-crystalline strata, &c., and according to this theory the ores of such veins may be derived from three sources, namely, from the incompletely decomposed remains of metalliferous silicates derived from the original crystalline rocks, from solution-products of older veins, and, finally, under special circumstances, from traces of the metals which are contained in sea water. The last source will probably have directly supplied only a limited number of deposits.

It has however been shown that the fresh mother-liquors from the salterns of the Mediterranean contain sufficient copper to be recognisable in 5 cc. of the liquid, at which rate one cubic metre of the water of that sea will contain at least 0·01 grm. of copper. The black and usually very sulphurous matter deposited in basins where sea water has been left to itself, constantly contains copper, and the same is generally true with regard to the dark-coloured gypseous muds of all ages. The copper schists of Mansfeld contain organic matter in considerable quantity, together with copper, and ammoniacal salts equivalent to 0·000816 grm. of ammonia per kilogr. of rock, easily recognisable in a few grms. Lithia is also present in sufficient amount to produce a very brilliant spectral line. These associations are exactly similar to those which occur in modern estuarine muds.[1]

According to recent analyses, the phyllites of the Erzgebirge and Fichtelgebirge are by no means rich in the heavy metals, but if a sufficient amount of the rock be operated upon, their presence can always be detected. The dark-gray phyllite of Schneeberg contains arsenic, cobalt, and nickel; while the Cambrian schists of Goldkronach afford arsenic, antimony, and lead. The sericite schists of the Taunus yield from 0·05 to 0·06 per cent. of cupric oxide.

Stratified rocks of purely neptunian origin, with the exception of limestones, consist chiefly of the débris, in a more or less finely-divided state, of older crystalline rocks. It is not to be expected that they will not have lost a portion of the heavy metals originally contained in the rocks from which they were derived, but some one or more of them may nevertheless be almost always

[1] L. Dieulafait, *Revue universelle des Mines*, vii. 1880, p. 425.

detected. H. Frick [1] first detected the presence of oxide of copper in clay slates; and by operating upon 1 lb. of roofing slate from Bangor, North Wales, Forchhammer [2] obtained a large quantity of lead, in addition to copper and zinc.

Bischof, many years since, expressed the opinion that if properly looked for, copper would be found in all clay slates, and subsequent investigation appears to go far in support of this view.[3] Sandberger discovered copper, zinc, lead, arsenic, antimony, tin, cobalt, and nickel in clay slates from the neighbourhood of Holzappel, as well as in those from Ems, and from Schulenberg, near Clausthal. Titanic and phosphoric acids also appear to be everywhere present in small quantities. Many rocks of New Red Sandstone age contain lead and copper. Lead, copper, arsenic and cobalt occur, in Germany, in the clay slates of the lower Keuper. The bituminous, marly slates of Raibl, in Carinthia, are rich in lead and zinc; but these metals are only obtained after fusion with an alkali, showing that they are present in the form of silicates only.

These investigations which have resulted in demonstrating the almost universal presence of heavy metals in rocks belonging to every geological period, tend greatly to enlarge our views on the subject of metalliferous deposits. It is undoubtedly possible that the filling of veins has often been derived, in a state of chemical solution, from the surrounding country rock, and the theory of lateral secretion appears to explain more satisfactorily than any other, certain phenomena not otherwise easily understood. It, moreover, not only accounts in a satisfactory way for the changes which take place in metalliferous veins when passing from one formation into another, but it also affords a reasonable explanation for the fact that shoots of ore usually follow the dip of the enclosing rocks.

It has been suggested by various geologists that certain strata, instead of being richer than others in metals, may possess a composition enabling them to act more efficiently in decomposing metalliferous solutions derived from other sources, and in depositing their contents in the form of ores. This reaction may perhaps sometimes influence the ore-bearing portions of a lode, but its importance may be regarded as secondary to the influence of the metalliferous contents of the rocks themselves.

[1] *Poggend. Annal.* xxxv., 1835, p. 193.

[2] *Ibid.*, xcv. 1855, p. 70.

[3] G. Bischof, *Lehrbuch der chemischen und physikalischen Geologie*, 1847, ii. p. 1900. English Translation, iii. 1859, p. 122.

Among the objections which have at various times been advanced against this theory may be mentioned the facts that different sets of fissures traversing the same formations often contain very different ores, and that when rocks of totally different character are brought by faulting to form opposite walls of a fissure, the ore may be, nevertheless, symmetrically deposited in corresponding layers. It may likewise be remarked that the same fissure frequently traverses several formations, and the character of the vein may throughout be essentially the same. It cannot however be doubted that the formation of lodes has been a long and complicated process, all the phenomena connected with which are not capable of explanation by any one cause.

Sandberger's theory has recently been adopted more or less completely by various American writers; thus Emmons[1] describes in detail the mode in which he considers the Leadville ore deposits to have been produced, and thus summarises his views on the formation of ore deposits in general:—

"1. Ore deposits have been deposited from solution, rarely in open cavities, most frequently by metasomatic interchange.

"2. Solutions do not necessarily come directly upwards, but simply follow the easiest channels of approach.

"3. The material was derived from sources within limited and conceivable distance, very often the older intrusive rocks."

On the other hand, this theory has been opposed by Blow,[2] who believes:

"That the (Leadville) ore deposits were formed through a molecular substitution and replacement of the dolomitic limestone by hot alkaline mineral-bearing solutions coming from *below*, or by metal-bearing waters and vapours from solfataric action following the ejection of the dyke porphyries, and consequent thereupon."

He concludes by pointing out that whilst it is impossible to demonstrate by direct proof that the mineral-bearing solutions came from below, yet that a consideration of all the phenomena makes it appear that there is but one source from which these solutions could be derived, namely, from below, and that such ore deposits were formed from hot metal-bearing solutions and vapours, which were forced up from the same deep regions and in

[1] S. F. Emmons, "The Genesis of Certain Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, xv. 1886, p. 125.

[2] A. A. Blow, "The Geology and Ore Deposits of Iron Hill, Leadville Colorado," *Trans. Amer. Inst. Min. Eng.*, xviii. 1889, p. 145.

the same manner as the intrusive dyke porphyries. These views will be considered more in detail under the next head, the theory of ascension, but meanwhile it may be noted that Emmons still maintains his views, as shown by his recent paper on the "Geological Distribution of the Useful Metals in the United States,"[1] in the course of which he states that "Chemical investigation of many eruptive rocks has detected the presence of gold and silver under such conditions as to leave little doubt that they were original constituents of the rocks"; and again, "For the original source of lead and zinc there seems no valid reason why we should not look to the massive eruptive rocks as in the case of other metals." In a discussion upon a paper of Prof. Pošepny's, to which reference will be made presently, Emmons[2] strongly emphasises his continued adherence to the lateral secretion theory, although he takes care to point out that the lateral secretion theory which he and American geologists of his school hold, is a much broader one than that originally put forward by Sandberger, in that the former includes the derivation of mineral constituents from rocks within reasonable proximity as opposed to unknown depths, whilst the latter derives them from the immediate walls of the veins; the exact direction in which the current of solution happens to be moving at the time of deposition being a matter of secondary importance according to this view. Besides him, a number of other American geologists, such as Blake, Winslow, and Le Conte, in the same discussion advocated more or less pronounced lateral-secretionist views, although they are not the extreme views originally propounded by Sandberger, but rather the modified views of Emmons as enunciated above.

Another American geologist of the same school is Becker, who has made a most careful examination of the deposits at Steamboat Springs and Sulphur Banks (*see* page 115), two localities which many ascensionists consider to afford almost demonstrative evidence of the correctness of their views. Becker, however, does not share this opinion, and states his conclusions on the subject as follows: "I regard many of the gold veins of California as having an origin entirely similar to that of the quicksilver deposits. . . . The evidence is overwhelming that the cinnabar, pyrite and gold of the quicksilver mines of the Pacific slope reached their present positions in hot solutions of double sulphides,

[1] *Trans. Amer. Inst. Min. Eng.*, xxii. 1893, p. 53.
[2] *Trans. Amer. Inst. Min. Eng.*, xxiii. 1893, p. 597.

which were leached out from masses underlying the granite and from the granite itself."[1]

If the term *lateral secretion* be employed in this modern, somewhat extended sense, and it be understood to imply that the solution, after becoming impregnated by its passage through the rocks, had free movement in the fissure, so that each molecule was not deposited where it issued in solution from the country, this theory passes directly into that of the ascension of aqueous solutions, and is one of the most widely held at the present day.

7. *Theory of Ascension.*—This theory in its earlier form supposes lodes to have been formed in part only, if at all, of minerals dissolved out of rocks in the immediate horizon of their several deposits in vein fissures, and that the chief portion of the material has been derived from greater depths by solvents circulating through the fissures. According to some who have advocated this theory, sublimation, either with or without steam, has also assisted in the formation of metalliferous veins. The increased heat and pressure, due to great depth, will greatly facilitate the solution of the different vein-forming substances, and minerals may be deposited in all parts of the fissure, although their constituents do not exist in the rocks in its immediate vicinity. These solutions will, under a pressure due to the height of the column, penetrate more or less deeply into the surrounding rocks, and may, under certain circumstances, give rise to their impregnation by metalliferous minerals. By the same agency the adjacent rocks are sometimes softened and decomposed to a considerable distance from the lode; or the country rock may, on the contrary, give rise to the formation of capels through becoming hardened by silification. Waters, possessing solvent powers vastly increased by high temperature and great pressure, percolating through rocks containing the heavy metals will gradually remove them, by lixiviation, together with other mineral substances, and these will again be deposited upon the sides of the fissure in proportion as the solvent power of the menstruum becomes lessened by diminishing temperature and pressure. On the other hand, it is probable that minerals diffused in rocks comparatively near the surface may have been removed by solutions which, penetrating into vein fissures, have mingled with the waters circulating through them. With regard to the precise chemical reactions which take place in the deposition of ores in mineral veins we have yet much to learn,

[1] G. F. Becker, "The Geology of the Quicksilver Deposits of the Pacific Slope," *United States Geological Survey*, xiii. 1888, p. 449.

but there can be no doubt that deposits somewhat akin to those of true veins are at the present time being formed by the action of certain thermal springs.

In a paper before referred to Newberry strongly advocates the theory of aqueous ascension, and appears to believe that no other is capable of explaining all the various phenomena connected with the formation of lodes. After briefly adverting to other theories he remarks:—"But argument is really wasted in a discussion of the filling of fissure veins, since we have examples that seem to settle the question in favour of chemical precipitation from ascending hot water and steam. In the Steamboat Springs of Western Nevada, for example, we in fact catch mineral veins in the process of formation. These springs issue from extensive fissures which have been or are being filled with siliceous veinstone, that carries, according to M. Laur, oxide of iron, oxide of manganese, sulphide of iron, sulphide of copper, and metallic gold, and exhibits the banded structure so frequently observed in mineral veins."

To this theory Sandberger objects, on the ground that none of the numerous mineral springs which he has examined, namely, those of Petersthal, Rippoldsau, Baden, Badenweiler, the Max-quelle of Kissingen, and others, deposit any mineral incrustation on the walls of their channels of exit, although they subsequently, upon exposure to the air, give rise to muddy deposits containing various heavy metals. The Sulphur Springs in Colusa County, California, and Steamboat Springs in Western Nevada, he regards as exceptional phenomena only to be compared with the unimportant metalliferous deposits produced by solfataras or fumaroles, or which issue from fissures in heated lava. He further remarks that with the exception of California no country, either in the new or old world, possesses ore deposits containing such masses of free sulphur. According to the same author the various metallic sulphides which so constantly occur in lodes are the results of the reduction of sulphates by the action of organic matter.

It may, however, be stated, on the other side, that the rule relative to the non-deposit of minerals in channels giving issue to hot waters is not without remarkable exceptions, since at Steamboat Springs an adit was driven in such a way as to intersect, at a considerable depth from the surface, a fissure which once formed a vent for mineral waters. At that depth the banded structure was not only continued, but the veinstone, which consisted chiefly of quartz, contained a notable proportion of cinnabar.

Sulphur is by no means abundant in the deposits of Steamboat

Springs, and is for long distances entirely absent. Native sulphur, however, occurs in the mineral veins of America, Australia, and some other countries. It has been found in the gold mines of Virginia and North Carolina, as well as in antimony reefs at Costerfield in Victoria, and in veins at Maldon, St. Arnaud, and Castlemaine in the same colony.

Sulphur is also of not unfrequent occurrence in the auriferous quartz reefs of Southern India, where, in the form of transparent crystals, it covers the surfaces of small druses in the veinstone. Specimens kindly forwarded to me by Mr. H. A. Severn from the Wynaad were in the form of octahedra, and had been deposited upon an extremely thin coating of ferric oxide lining a cavity, the length of the greater diameter of which was about one inch. It is evident that the presence of sulphuretted hydrogen may sometimes account for the formation of certain metallic sulphides, without the intervention of organic matter.

The ascensionist theory, so strongly combated by Sandberger, has of recent years received most powerful support from the studies and writings of Pošepny, who as lecturer on mining geology (*Montangeologie*) at Přibram, founded a fresh school of ascensionists, which has a powerful following amongst German geologists; his principal writings on the subject are his monograph on the "Genesis of Ore Deposits,"[1] and his *Archiv für Practische Geologie* (1880–1895). He points out that there are two systems of water circulation in the earth's crust, one that of surface waters, absorbed by the earth and given out again at such points as the contour of the land admits of, which he proposes to call the *vadose* circulation, and another that of waters below the permanent water level, or the deep underground circulation, the possibility of such movement of water downwards in spite of the constantly-increasing pressure having been shown experimentally by Daubrée.[2] The former is an oxidising water-current, more prone to dissolve mineral matter than to deposit it, and circulates freely in spaces that may be partly filled with air. The latter will have its solvent powers immensely increased by high temperatures and pressures, and is likely to dissolve mineral matter as it descends through the pores of rocks, and to deposit it as it ascends through open fissures; all fissures below the permanent water level are necessarily, however, full of water. For this latter reason Pošepny holds that Sandberger's views as to the seepage of mineralising solution into

[1] *Trans. Amer. Inst. Min. Eng.* xxiii. 1893, p. 197.

[2] *Études Synthétiques de Géologie Expérimentale*, i. p. 235.

fissures from the walls of veins cannot possibly be correct; he also endeavours to throw doubt upon the methods of analysis, by which Sandberger had proved the presence of minute quantities of various metals in the eruptive rocks associated with the Přibram veins; in this he is supported apparently by Stelzner, who holds that these methods of analysis do not show whether the heavy metals, which were undoubtedly detected, were original constituents or secondary impregnations. Pošepny argues that since the mean density of the whole earth is 5·6, and that of the rocks forming its crust only 2·5, the central nucleus of the earth must be much denser, so that the deep region—his *barysphere*—must be the peculiar home of the heavy metals, and such of them as are found in our metalliferous veins must have been brought up from it in aqueous solution. According to his latest work,[1] he declares that he knows scarcely another deposit that argues as distinctly for the ascensionist theory as that of Přibram. "The structure of the minerals forming the vein shows the slow rate of their formation and the manner in which the vein has been filled by them. To an unprejudiced observer they correspond most closely to precipitates from dilute solutions in a state of circulation, and are not to be compared to deposits from a corked bottle of mineral water. These precipitates cover the entire wall space of the channel through which the fluid circulates, and form as a rule symmetrically disposed mineral crusts, which fill the cavity all except its central 'vugh.' Judging from their mode of occurrence, the lateral secretion theory must be absolutely excluded." This arrangement of mineral matter (his *crustification* as opposed to stratification) forms the basis of many of his strongest arguments.

The ascensionist theory has many followers in America, the chief of whom perhaps is R. W. Raymond, who adopts these views almost in their entirety. As matters stand at present, however, the general arguments of American geologists have tended rather to minimise the difference between the two opposite theories; Pošepny and Sandberger seemed rather in their discussions to desire to accentuate the differences between their views, whilst such American writers as Emmons, Raymond, and Le Conte have attempted to multiply points of concordance. The latter writer has contributed an excellent paper to the discussion,[2] in which he shows that, accepting the figures quoted by Pošepny for the mean density of the earth, the increase in density at a depth of 100

[1] *Archiv für Practische Geologie*, 1895, p. 743.

[2] *Trans. Amer. Inst. Min. Eng.*, xxiv. 1894, p. 996.

miles would be only 0·3, and therefore the mean density 2·8, which is about that of the more basic eruptive rocks, whilst it is highly improbable on the other hand that circulating water could come up from as great a depth as 100 miles below the surface of the earth ; he considers that the limit of circulation would be reached at a depth of 8 to 10 miles, and argues that ascending water currents are rich in metallic contents, "not because they have traversed a barysphere, but *because they have traversed a thermosphere*." His summary of his own views, intermediate to some extent between the lateral secretionist and the ascensionist schools is worth quoting *in extenso* :—

"The source of metals is, indeed, on the one hand, by leaching, but not by lateral secretion; on the other hand, not from a hypothetical barysphere, but from the wall rock; though again, not from all parts alike, but mainly from the deepest parts, and even from below the deepest parts, of sensible fissures. As in the case of many other disputes, I believe both sides are right and both are wrong. Ascensionists are right in deriving metals mainly by ascending currents from great depths, but wrong in imagining these depths to be an exceptionally metalliferous barysphere. They are wrong also in not allowing subordinate contributions by lateral currents from the wall-rock higher up. The lateral secretionists, on the other hand, are right in deriving metals by leaching from the wall-rock, but wrong in not making the main source the thermosphere.

"In the uncoloured light of a more comprehensive view, many of the difficulties and obscurities of the subject disappear.

"1. Ore-deposits, using the term in its widest sense, may take place from many kinds of waters, but especially from alkaline solutions; for these are the natural solvents of metallic sulphides, and metallic sulphides are usually the original form of such deposits.

"2. They may take place from waters at any temperature and pressure, but mainly from those at high temperature and under heavy pressure, because, on account of their great solvent power, such waters are heavily freighted with metals.

"3. The depositing waters may be moving in any direction—up-coming, horizontally moving, or even sometimes down-going, but mainly up-coming, because by losing heat and pressure at every step, such waters are sure to deposit abundantly.

"4. Deposits may take place in any kind of waterways—in open fissures, in incipient fissures, joints, cracks, and even in porous sandstone, but especially in great open fissures, because these are the main highways of ascending waters from the greatest depths.

"5. Deposits may be found in many regions, and in many kinds of rocks, but mainly in mountain regions and in metamorphic and igneous rocks, because the thermosphere is nearer the surface, and ready access thereto through great fissures is found mostly in these regions and in these rocks."

It will be seen that the above is an enunciation of the ascensionist theory that differs widely in many respects from that of Pošepny, quite as widely indeed as the views of Emmons differ from those of Sandberger, and that the respective theories as set forth by the American geologists are in far closer accord than are those of the German professors of these theories, and in so far are probably a good deal nearer to the real truth.

Metallic minerals, especially specular iron ores, are sometimes deposited by sublimation in the crevices of cooling lavas, and it is probable that in certain solfataras, like that near Borax Lake, in California, the concentration of a portion of the cinnabar and other substances present may be partially due to this agency. Many bodies which are not easily volatilised are readily carried along by a current of steam or aqueous vapour. There is, apparently, no reason for believing that sublimation has usually acted an important part in the formation of true veins, notwithstanding the fact that free sulphur sometimes occurs in metalliferous veins.

General Conclusions.—It will be clearly seen from the above quoted views of various writers on the subject that the mode of formation of metalliferous veins is very far indeed from being understood. The manner in which fissures were produced seems tolerably clear, and there is practically a consensus of opinions on that point. The manner in which the minerals were deposited therein admits however, as has just been shown, of very various interpretations. Even the statements upon which the opposing theorists base their arguments are not by any means unchallenged by their opponents, and even if they were, most of them admit of diametrically opposite explanations. Thus, if it were definitely proved that the rocks within reasonable distance of a fissure vein contain minute proportions of the same metals as are found in the vein, one side would see in this fact a proof that the metals in question were derived from the rocks, whilst the others would argue that the metals in the rocks were derived from the vein; or, if it were proved that no such metals exist, one side would claim this as evidence that the metals had all been leached out, and the other as proof that no such leaching had ever been possible. It may be noted that the discussion is not confined to true fissure veins, but is necessarily extended to all epactic ore deposits and must include also group *d* of symphytic deposits, because all of these deposits have probably received their precious metals from the same sources.

It may be taken for granted that certain ores and certain deposits have been formed at shallow depths from the superficial circulation; we have indeed proof of this in the cinnabar deposits at Steamboat Springs and Sulphur Banks. R. W. Raymond[1] has described the formation of galena above permanent water level, by the reducing action of decaying wood upon water carrying sulphate of lead in solution. Iron ores and manganese ores are no doubt at times deposited also by the superficial or vadose circulation; indeed with the except of tinstone it may be fairly presumed that all deposits of oxidised ores are either deposited by shallow waters, or are the result of their oxidising action upon ore bodies already in existence. The problem is therefore restricted to the remaining ores, which are for the most part sulphides, occasionally oxides like cassiterite or native metals like gold. It seems beyond doubt that all of these were brought to the places they now occupy in solution in water in some form. Alkaline waters, saline waters, water containing carbonic acid and sulphuretted hydrogen under pressure, and water itself at high temperatures—one or other of these solvents will dissolve every metal in some form or other. When solutions thus formed meet with precipitants of the metal they carry, or when under diminished pressure they give off the gases they held dissolved, or when they are cooled down from any cause whatever, they naturally deposit the metals which they had dissolved. This seems to be almost as far as we can at present trace back with anything like certainty the genesis of ore deposits. Whence the metals were primarily derived must still remain an open question. We know on the one hand from Daubrée's experiments that heat and pressure greatly increase the solvent powers of water; on the other hand we know that water can no longer remain water once its critical temperature of 370° C. is exceeded, and it is therefore hard to imagine that at higher temperatures than this it could still exert any solvent powers. This critical temperature should be reached at a

[1] Discussion, *Trans. Amer. Inst. Min. Eng.* xi. 1883, p. 120.

depth of about nine miles below the surface, assuming that the average rate of increase near the surface, or about 1° C. for every 125 feet of depth, is uniformly maintained. On the other hand, water vapour cannot exist under a pressure exceeding 196 atmospheres, which pressure would be produced by a water column of about one and a quarter miles in depth, so that it seems fair to assume that below nine miles or thereabouts water as such could not possibly exist, but would be split up into its constituent gases, so that solution in the ordinary sense could not take place at what may be called comparatively shallow depths. Heim's opinion that no open fissures can exist below 15,000 feet of depth has already been quoted. Taking these data in connection with the calculations of Emmons already quoted, it would seem as if we should be compelled to assume that the region of solution within which the various metals can be dissolved by water—the thermosphere of Emmons—is limited to a depth of nine or ten miles, though it must be borne in mind that we have no certain knowledge of the physical conditions prevailing under such circumstances. There is no difficulty in admitting that water can penetrate to this depth in the manner illustrated by Daubrée's experiment (p. 138). It is also possible that osmotic pressure might play a part in promoting circulation. A fissure whose walls are coated with gelatinous silica or any other colloidal substance, outside of which water is descending and dissolving metallic and other compounds as it moves downward, whilst the fissure is filled with the comparatively concentrated solution thus produced, would form a system in which circulation could quite conceivably be maintained by osmotic pressure. This force would thus cause a seepage from the walls into the fissure, although such seepage seems to be looked upon as impossible by Pošepny. In spite of all that has been done and written on this subject we are still reduced to mere conjecture on two of the most important elements in the inquiry, whence the metals were dissolved and how they were precipitated. It is only safe to affirm that they were in very many cases introduced in the form of solutions.

One of the most important changes that has been introduced recently into our conceptions of the genesis of ore deposits, due chiefly perhaps to Emmons and Pošepny, although they have been in part anticipated and have had many followers, is the recognition of the prevalence of metasomatic action and the limitations imposed upon the old views respecting fissure veins. The typical fissure veins of the older writers,—veins with two well-marked walls slickensided and covered with flucan, containing a series of minerals differing widely from those contained in the country rock, and enclosing fragments of country rock, the stratification or cleavage of which is not parallel to that of the rock *in situ* in the walls,—such veins do indeed exist, but they are both few in number and of comparatively small importance, because their size is generally not great. The miner knows to his cost the enormous difficulty of keeping the walls of even a moderately wide vein open, when the vein matter has been removed. The pressure tending to force the walls together must be infinitely greater at such depths below the surface as those at which mineral deposition is supposed to take place, and although the fact of the fissure being full of water would tend to keep the walls apart, it is nevertheless difficult to conceive how a very wide fissure could remain open at great depths long enough to be completely filled with deposited minerals. It is far more usual to find veins without any defined walls at all than with two. Many veins have but one well-marked wall, and this one will perhaps be found to be the foot wall more often than the hanging. In such cases, instead of a definite wall we find the vein-stuff passing by insensible gradations into the country rock, and the deposit is taken out by the miner just as far as it is found rich enough to be worth working. In some cases where no definite walls are to be seen, central fissures may or may not be traceable. Closely allied to this form of deposit is one often met with in tin lodes, where a central fairly defined vein exists, carrying tinstone, whilst the rock on either side is impregnated with tin ore to such an extent as to render it worth working.

FIG. 46.—Impregnation of tin ore at East Huel Lovell.

A typical lode of this kind is that at East Huel Lovell, in the parish of Wendron, which has been well described by C. Le Neve Foster.[1] Fig. 46 represents a horizontal section of this deposit as seen at the 100-fathom level, in which *a b* is the *leader* or *divider*, a small vein composed of quartz and ferruginous clay varying from ¼ to ½ inch in thickness. The dotted portion is the tin-stuff, outside which is the ordinary granite of the district. This granite is well marked and encloses large crystals of orthoclase; whilst the stanniferous portion consists of a mixture of quartz, mica, gilbertite, and cassiterite, with a little fluor spar, iron pyrites, copper pyrites, erubescite, copper glance and chalybite. Gilbertite, a crystalline alteration-product of felspar, is frequently abundant. There is no wall or selvage between the tin-bearing mass and the surrounding granite, the two gradually merging into one another; and, following the leader along its strike, the tin-bearing rock decreases in width until at last both walls of the vein are composed entirely of granite. The shoot of tin at the 100-fathom level was about seven fathoms in length, the richest part having a length of three fathoms and a width of nearly nine feet. In some cases the oxide of tin lay entirely on one wall, as shown in Fig. 47, but the prevailing characteristics namely, the leader of quartz, the absence of any wall between the tin and the granite, and the general composition of the tin ground, always remained the same. The main shoot of tin ore at East Huel Lovell has been followed from the 40-fathom level down to the 110 as one continuous pipe, and is in the shape of a long irregular cylindroid with an elliptic base generally about fourteen feet long by seven wide.

FIG. 47.—Impregnation of tin ore at East Huel Lovell.

M. Daubrée, some forty years ago, first called attention to the fact that, with the exception of quartz, the minerals most constantly associated with tin ore are compounds containing fluorine, principally fluosilicates, such as lepidolite and topaz; sometimes also fluophosphates and fluorides, the latter being present chiefly as fluor spar.[2]

[1] *Trans. Roy. Geo. Soc. of Cornwall*, ix. 1876, p. 167.

[2] "Mémoire sur le gisement, la constitution, et l'origine des amas de minerai d'étain," *Annales des Mines*, xx. 1841, p. 65; *Études Synthétiques de Géologie Expérimentale*, Paris, 1879, p. 29.

Boron is a constituent of the minerals tourmaline and axinite, both of which are frequently present in tin deposits; whilst the other most commonly associated elements are tungsten, molybdenum, phosphorus, arsenic and iron. He arrives therefore at the conclusion that tin ore, fluorine compounds, and borosilicates owe their origin to the same set of reactions, and supposes that the tin, tungsten, molybdenum, boron, phosphorus, and a portion of the silicon came up through fissures from some deep-seated source as fluorides. Finally, he suggests that the present condition of *Stockworks*, which consist of quartz, tin ore, silicates, fluosilicates, and borosilicates, resulted from the action of these fluorides, probably in the presence of water, on the enclosing rocks.

In a subsequent memoir Daubrée gives the results of numerous experiments, which he made with a view to imitating the processes by which nature may have acted in forming such minerals.[1] Instead of employing fluorides, which are not so readily made or so easily managed, chlorides were generally used, since, from the great analogy which exists between fluorides and chlorides, it was considered that any results obtained with the latter might safely be supposed to occur with the former.

The first experiment consisted in passing a current of stannic chloride together with a current of steam through a red-hot porcelain tube. In this way double decomposition was effected and crystals of stannic oxide were deposited on the interior of the tube. The crystals of oxide of tin thus obtained are sometimes colourless and transparent, and at others exhibit tints of brown or green, the different coloured specimens being all associated in the same groups. Their specific gravity is 6·72; they readily scratch glass; and when mixed with carbonate of sodium they yield a globule of tin before the blowpipe. Although exceedingly minute, the crystals so obtained exhibit well-defined faces and angles, but they are so entangled with one another that it is difficult to determine their form. The temperature of the portion of the tube on which the crystals of oxide of tin were deposited did not exceed 300° C., being rather below the melting point of lead. Titanic chloride treated in the same way yielded crystals of brookite, while a deposit of vitreous and, in part, crystallised quartz was obtained from chloride of silicon and steam. In 1851

[1] "Recherches sur la production artificielle de quelques espèces minérales cristallines, particulièrement de l'oxyde d'étain, de l'oxyde de titane, et du quartz. Observations sur l'origine des filons titanifères des Alpes," *Annales des Mines*, xvi. 1849, p. 129. *Géologie Expérimentale*, p. 37.

Daubrée obtained well crystallised apatite by passing perchloride of phosphorus over lime at a dull red heat, and a mineral analogous to topaz was produced by the action of a current of fluoride of silicon on alumina at a white heat.[1]

The circumstance before referred to (p. 32) of deers' antlers more or less completely replaced by crystallised oxide of tin having been found in various Cornish streamworks, affords, however, sufficient evidence that this mineral has sometimes been deposited at ordinary temperatures. In the case in question it would appear not improbable that the production of alkaline carbonates through the decomposition of felspars, may have been an important factor in the solution and subsequent deposition of oxide of tin.

This form of vein together with its altered walls has been described as a separate class of deposit under the title of "impregnation"; it seems however better to consider them as true fissure veins, seeing that they decidedly owe their origin to fissures. A closely allied class is that of stockworks, into which the above passes by insensible gradations. It is perhaps best to maintain the division, somewhat artificial although it may be, by classing such deposits when more or less tabular in form and referable to a single fissure as veins, and by calling them stockworks when they assume a form in which their three dimensions are more nearly equal and when they owe their origin to a large number of irregular reticulated fissures.

Referring again to Daubrée's experiment in which he produced fissures and faults by vertical pressure (page 82) it will be seen that he proved that the formation of such a fissure would be accompanied by the production of a number of very fine cracks in the walls of the main fissure. Solutions circulating in the latter would therefore necessarily find their way through the former, and if the wall rock consisted of some easily decomposable or soluble rock, it is perfectly intelligible that the whole of the rock thus shattered would become mineralised both by deposition of ores in the fissures, and by the metasomatic action of the solution or the removal of some of the ingredients of the shattered rock, and the deposition of mineral in its place, this mineralisation extending as far as the rock had been thus physically prepared for the passage of the solutions. If it so happened that this shattering

[1] "Expériences sur la production artificielle de l'apatite, de la topaze, et de quelques autres mineraux fluorifères," *Annales des Mines*, xix. 1851, p. 684; *Géologie Expérimentale*, p. 48.

was confined to one side of the fissure a mineral vein with one well-marked wall only (the opposite side) would be formed, there being no other wall strictly speaking. Or again a whole belt of country between two parallel fissures, not very far apart, may be shattered in this way and rendered permeable by solutions. There can be very little doubt but that most wide veins have been formed in such a way as this, and that the material of which the vein consists is very often shattered country rock mineralised *in situ*, rather than the filling of an empty fissure by introduced mineral matter. This remark applies equally to bedded and contact veins, the genesis of which seems to be, as regards their mineral contents, precisely similar to that of fissure veins; in this connection the studies of Emmons on the Leadville deposits may be mentioned. They will be more fully referred to again subsequently (*see* page 162).

A kind of fissure vein that is often described as a separate class is that known as *fahlbands*, a term that seems to have been indiscriminately applied to both the veins and the rocks in which they occur. These fahlbands, which have already been referred to on page 112, are simply beds of slate of a fawn colour within which certain fissure veins are abnormally rich. Their typical development is at the celebrated silver mines of Kongsberg, in Norway, which were discovered in 1623, and worked with comparatively little interruption from that date to the present time; they are situated in a district consisting chiefly of gneiss, gabbro, mica schist, hornblende schist, talc schist, and chlorite schist. The silver ores occur in these typical *fahlbands*, which consist of parallel belts of rock, of considerable width and extent, impregnated with sulphides of iron, copper and zinc, and sometimes also with those of lead, cobalt and silver. The iron pyrites often becomes, to some extent, decomposed near the surface, giving rise to the formation of hydrated ferric oxide and producing a kind of gossan, which is locally regarded as an indication of the presence of silver ores. These fahlbands, or gray beds, have a direction very nearly north and south. They are irregular in their dimensions, the greatest breadth of any one of them being about a thousand feet; but they constantly preserve a considerable degree of parallelism with one another, and may be traced upon their line of strike, for a distance of several miles.

The amount of ore disseminated through such beds is usually very small, and in but a few localities only has it been found sufficiently concentrated to admit of its being profitably worked.

In the Kongsberg district there are several of these fahlbands, parallel in strike and inclination with the gneissoid and schistose strata in which they occur, and subject to the same local disturbances of stratification. They are themselves traversed by fissure veins containing silver ores, and long experience has shown that these are productive only where they intersect fahlbands. The veins, which are numerous, course nearly east and west, almost at right angles to the strata and fahlbands, and generally dip towards the south, although a few of them incline in the opposite direction. As a rule they are but a few inches in breadth, seldom exceeding a couple of feet, and their narrower portions are usually richer in silver than the broader parts, which are chiefly made up of non-metalliferous veinstone. Their breadth is stated to increase up to a certain depth and then gradually to diminish; the portions having a thickness of about one inch being on an average the richest. When two such lodes intersect within the limits of a fahlband, the result is often a considerable pocket of ore. The lodes are without selvages, and are firmly attached to the wall rock, which for some distance is often impregnated with silver ores.

Numerous other instances can be quoted in which the value of the vein is dependent upon the strata which it happens to traverse. Well-marked examples can be quoted from the lead veins of Durham and Cumberland and of Derbyshire, which are rarely productive, except when they traverse limestone strata, or at any rate are never as rich in other rocks. This would seem to be an immediate consequence of the far more ready solubility of limestones than of the other strata. This same reason probably accounts for the fact that very many ore deposits are to be found in limestone or dolomitic areas (with the exception of gold veins). These latter however, when typical gold quartz veins, seem very often to be true fissure veins with well-marked walls, and it is probable that the solutions (most likely alkaline[1]) that carried the gold and silica were not such as would readily give rise to metasomatic reactions with calcareous rocks, but would rather be capable of decomposing siliceous ones.

Typical examples of fissure veins may be quoted from any of the larger mining districts, such as Cornwall, Alston Moor, Freiberg, &c. It is not however easy to point to a vein in the formation of which metasomatic action has played no part

[1] H. Louis, "The Mode of Occurrence of Gold," *Mineralogical Magazine*, x. No. 47, p. 241.

whatever and which has been produced entirely by the filling of a fissure. Perhaps the best example of such a vein is to be found in mineral veins that occupy the space between the walls of fault fissures, such as some of the smaller lead veins of Alston Moor, when not in limestone.

GROUP *b*. BEDDED VEINS.—Metalliferous deposits belonging to this class differ from true veins inasmuch as they are conformable with the bedding or foliation of the country rock, whereas true veins traverse all formations independently of stratification and foliation. As in the case of ordinary lodes, the gangue of *bedded veins* differs entirely from the surrounding rock, the veinstone, which frequently consists of quartz, being often crystalline and exhibiting a distinctly banded structure. It need hardly be said that such veins are liable to be faulted together with the strata

FIG. 48.—Bedded veins.

enclosing them, and may exhibit any of the phenomena of faulting previously investigated. Besides extending uninterruptedly for considerable distances, deposits of this class sometimes form lenticular masses of limited extent; these are, however, often followed by others of a similar description forming a series resembling a more or less interrupted lode. The quartz veins so numerous in Canada, New England, and in the Alleghany Mountains, are generally examples of deposits of this class, as are some of the auriferous veins of California. Fig. 48 represents an ideal section of this form of deposit. The ore-bearing mass does not always crop out at the surface, although it frequently does so; *a* is a vein which makes its appearance at the surface, *b* does not reach so far, while *c* is a somewhat lenticular vein extending but a short distance either upwards or downwards. One of the most important constituents of bedded veins is gold, with which either pyrites, blende, galena, or chalcopyrite is almost always, to some extent, associated. It was formerly believed that veins of this description are less persistent than true lodes, that they are richer nearer the surface than elsewhere, and that they frequently terminate by pinching out both in depth and in horizontal extension. Recent mining operations have, however, materially modified the received views respecting the value and persistency of bedded veins. Many of them are of great thickness and extent, and after having been worked to very considerable depths, have been there found as productive as they were nearer the surface. The character of the veinstone of such deposits frequently appears to in no way vary from that of true fissure veins, from which they often differ in no respect except that their course is parallel to that of the strata between which they lie.

There seems to be little or no doubt that the minerals contained in bedded veins and those in fissure veins have been deposited in the same manner and by the same agencies. The minerals themselves are for the most part identical, though it is possible to name a few minerals, such as cassiterite and chromite, which, being generally associated with igneous rocks, rarely if ever occur in bedded veins, which latter can obviously only be found in stratified formations. The real difference between the two groups is in the manner in which the cavities that the veins occupy were formed. The one, as we have seen, is due to a fracture of the strata, whilst the other is either a plane of weakness between the beds, or is produced by foliation or by contortion or bending of the strata which afforded a means of access to mineralising solutions, or produced spaces within which mineral matter might be deposited. Of course it is quite possible that a true fissure might be formed mechanically, perfectly parallel to the stratification; such a fissure if filled with mineral matter might be classed either as a fissure vein or as a bedded vein, according as genetic or morphological characteristics were deemed the more important in the system of classification. These two groups on the one side and that of altered beds on the other run more or less into each other and are often most difficult to discriminate.

Good examples of bedded veins are to be found in the gold-quartz veins of Nova Scotia; these are narrow veins 4″ to 24″ in width, striking about east and west, and dipping south at high angles of about 75° to 85°; they are parallel to the formation, which is supposed to be of Cambrian or lower Silurian age. The strata consist of hard slates alternating with black, very hard quartzites, locally miscalled whin rock. The veins are filled with white quartz, which occasionally has thin films of slate running through it parallel to the stratification and occasionally too encloses fragments or small horses of the wall rocks. The accompanying minerals besides gold are arsenical pyrites, iron pyrites, copper pyrites, galena, zinc blende, and calcspar, the latter often well crystallised. In some instances the slate of the walls is rather soft and is mineralised by arsenical pyrites. The veins pinch out at times and then come in again, sometimes a little above or below the course of the first vein, and there is abundant evidence in their structure and mode of occurrence to prove that they are really veins and not altered beds.

Some of the veins are intercalated between slates and quartzite ; it is nevertheless proper to classify them all as bedded veins and not as contact veins, firstly because these two rocks belong to

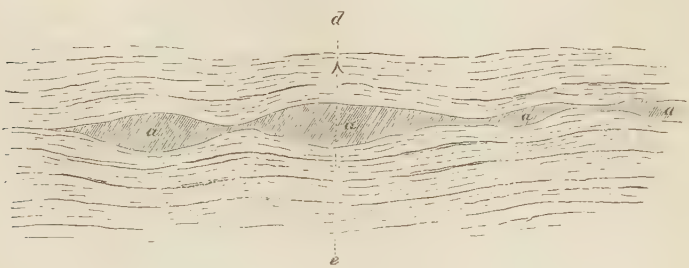


FIG. 49.—Lenticular deposits ; plan.

the same formation and are similar, being evidently but extreme cases of the metamorphism of beds of sand and of mud, all stages between which may be represented, and secondly and especially because the formation of the vein was not due to the fact that this was a plane of contact, the latter circumstance being, so to speak, accidental and not essential to the origin of the vein. This is an instructive instance of the reasoning that has to be followed in the classification of mineral deposits ; hard and fast lines cannot well be drawn between the different groups, and in assigning its place to any deposit, all the conditions affecting both the deposit and the rocks enclosing it must be taken into consideration.

Deposits of auriferous quartz, cupriferous iron pyrites, and some other minerals, occasionally assume the form of a series of lenticular masses, which lying between the foliations of the strata, follow one another both in length and depth in such a way as to constitute an interrupted vein. Fig. 49 represents in plan, and Fig. 50 in section on the line *d e*, a deposit of this kind, in which *a* indicates masses of either veinstone or ore. Such lenticular masses, which are often approximately continuous and lie at low angles, are described as beds, *Lager*, by v. Groddeck. They, however, occasionally enclose fragments of the country rock both from the foot and hanging walls, and, in such cases, cannot be regarded as contemporaneous with the enclosing strata, but are evidently of subsequent formation, and are therefore properly classed as epactic. Certain deposits, however, somewhat similar in character have probably had a different origin, and may be regarded as beds formed prior to the deposition of the overlying rock. When these lenticular deposits are of great width as compared to their extension, and hence lose their tabular character, they approximate

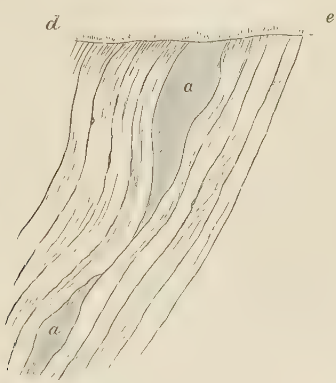


FIG. 50.—Lenticular deposits; section on *d e*.

closely to irregular deposits, and would be so classed in accordance with the system of classification here pursued, more especially if their genesis seems, as is very often the case, to be connected with igneous rocks in near proximity or in contact with them. The great similarity between these two groups will at once appear on comparing Figs. 48 and 66. Similarly shaped deposits wholly enclosed in igneous rocks could obviously not be classed as bedded, but must be looked upon as irregular deposits, and it is quite a matter of opinion where the line should be drawn between the two classes. Thus the deposits of cupreous pyrites at Huelva and other places would undoubtedly by many be classed in this group, nor can it be said that such an arrangement would be decidedly wrong.

Deposits of ore sometimes take place at the intersections of the main joints of certain rocks. Fig. 51 represents, in plan, an example of this kind of formation described by W. J. Henwood as occurring at Dhunpoore Mine, North-western India, where patches of chalcopyrite and erubescite *a* occur at the intersections of a series of joints *b* and *c* which traverse nearly at right angles a

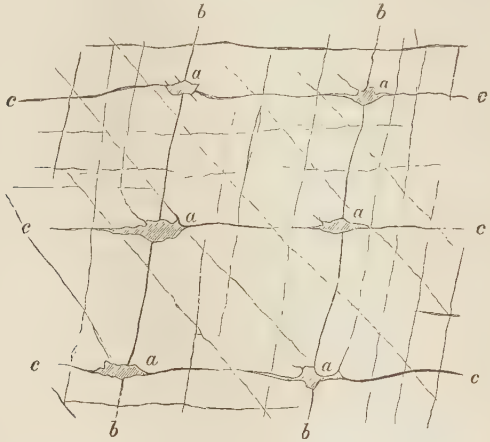


Fig. 51.—Bunches of ore at intersections of joints.

somewhat calcareous clay slate. Compare too the formation of gash veins and pipe veins in highly jointed limestone beds which exhibit quite similar appearances; these again might also be classed as irregular deposits.

An interesting modification of bedded veins is to be found in the so-called *barrel quartz* of Waverly, Nova Scotia. This con-

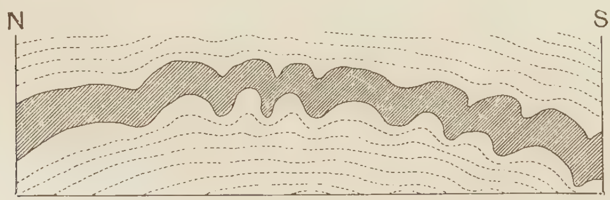
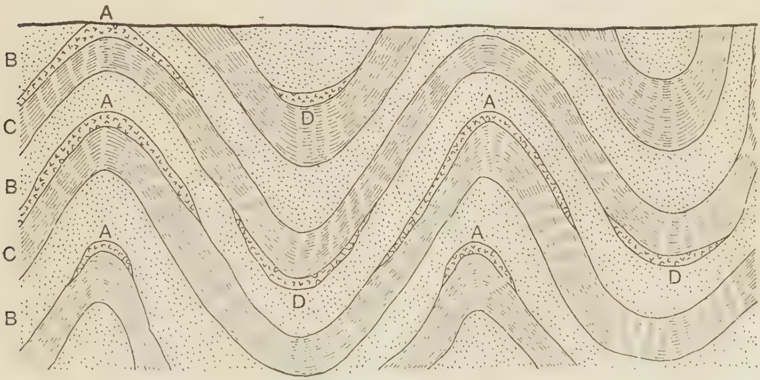


Fig. 52.—Section of "Barrel" quartz vein.

sists of an almost horizontal bed of quartz apparently occupying the central portion of an anticlinal fold; it has been subjected to some kind of crumpling action that has thrown it into a succession of sharply marked corrugations, looking, where the reef has been stripped and is being worked opencast, like a succession of rows of barrels (Fig. 52) lying on the floor of the workings, the axes of the "barrels" running about east and west. The thickness of the veins varies from a few inches up to four feet. The composition of the gangue is like that of the ordinary bedded veins already described, which may well indeed be a continuation in depth of the same vein. This barrel quartz is usually rich, the smaller barrels being the more productive. The stratification of the country rock is somewhat obscure, but seems to follow the curves of the barrels.

Another special form of bedded veins is what are known as *saddle reefs*, whose occurrence seems to be limited to Australia. Their especial habitat is the well-known gold mining district of Bendigo or Sandhurst, in Victoria. No better description of this



A.—*Saddle Reefs.* B.—*Sandstone.* C.—*Slate.* D.—*Inverted Saddles.*

FIG. 53.—Ideal section of saddle reefs.

form of vein is to be found than the following brief one by Mr. E. F. Pittman,[1] from whose paper the subjoined ideal sketch (Fig. 53) is also reproduced: "The country rock at Bendigo consists of highly contorted slates and sandstones which are of Lower Silurian age. The contortions of these slates and sandstones have assumed the forms of anticlines and synclines. If a quire of paper be placed flat upon a table and lateral pressure be exerted against the sides, it will be found to form saddles and troughs, or anticlines and synclines, corresponding with the contortions of the Bendigo rocks, which have in fact been produced in an analogous manner; and it will be noticed that spaces will be

[1] Edward F. Pittman, "On the Geological Occurrence of the Broken Hill Ore Deposits," *Records of the Geological Survey of New South Wales*, 1892, iii. part ii. p. 45.

formed between the sheets of paper, more particularly at the upper parts of the anticlines and the lower parts of the synclines, corresponding exactly with the fissures in which the saddle reefs of Bendigo were deposited.

"The reefs at Bendigo are associated with narrow intrusive dykes of dark gray dolerite, which have probably had some influence upon their auriferous contents.

"One of the chief points of interest about the saddle reefs of Bendigo is, that while the 'legs' of the saddles are invariably found to thin out and disappear in depth, the permanence of the mines is assured by the certainty of other saddles being discovered almost perpendicularly under the first, and at greater or less intervals of depth."

To the above description it need only be added that if the sheets of paper of Mr. Pittman's experiment be replaced by a series of layers of some thick material like thick felt or sheet india-rubber, whilst lateral pressure is applied between two vertical boards, the formation of the spaces at the apices of the folds will be even more clearly marked; their production depends indeed on purely geometrical considerations, the outer surface of each layer being necessarily less sharply curved than the inner surface of the next succeeding one, so that a certain area must be included between the segments of the curves thus formed, the greatest thickness of which lies in a line at right angles to the direction of pressure, whilst it tapers down to nothing at the points of maximum pressure. The formation of these saddles is therefore independent of the composition of the layers which form the walls; these may be either different rocks or the same, without affecting the character of the deposit. In conformity with the principle previously laid down we accordingly classify them as bedded and not as contact veins. In the Bendigo district many of the saddles are between slate and sandstone, as shown in Mr. Pittman's ideal section. Fig. 54, taken from Mr. Rickard's[1] paper on the Bendigo gold-field, shows a section across the Great Extended Hustlers, in which both walls of the saddle are in sandstone. Fig. 55 shows a section across the New Chum Consolidated Mine, taken from the same paper, in which the structure of a typical saddle is well shown. Each fold forms what is known as a "line of reef," all of which run approximately parallel, bearing N.25°W.—S.25°E., so that the respective legs of the saddles are spoken of as the east and west legs.

[1] T. A. Rickard, "The Bendigo Gold-field," *Trans. Amer. Inst. Min. Eng.*, 1891, xx. p. 499.

There are some eleven of these lines of reef recognised, of which three, the New Chum, the Garden Gully, and the Hustlers, are by

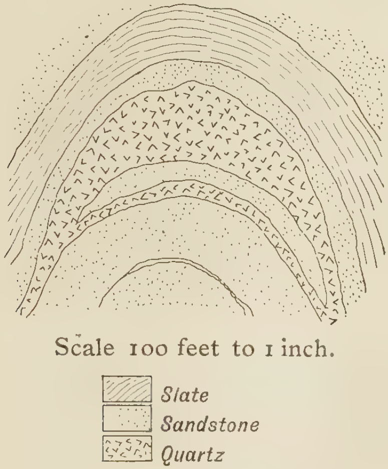


FIG. 54.—Section across Great Extended Hustlers' Mine.

far the most important. The first named has been followed for a distance of fourteen miles, the second for seven, and the last for

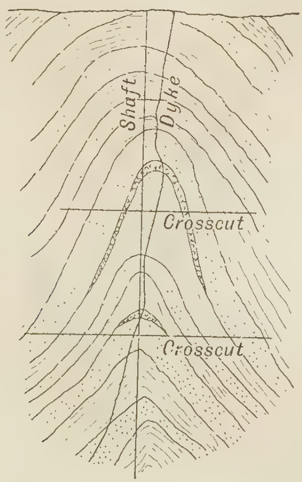
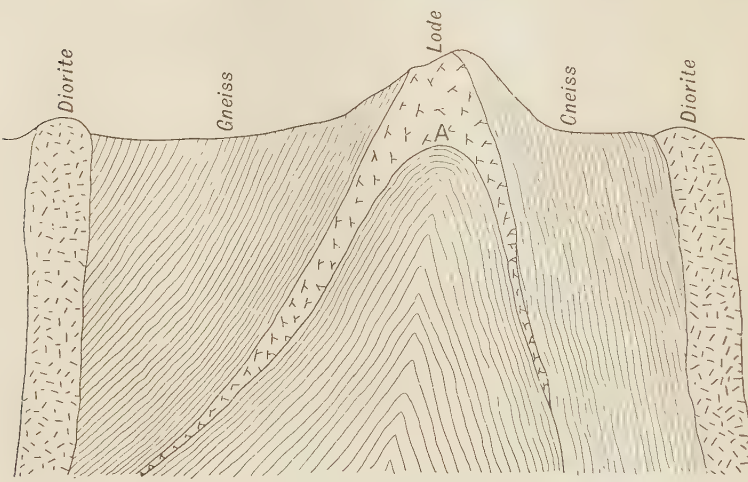


FIG. 55.—Section across New Chum Mine.

five miles, whilst the New Chum has been sunk upon for a vertical depth of over half a mile. It is to be noted that the anticlinal axes are not horizontal but have a dip averaging about one in twelve, sometimes to the north, but sometimes also to the south (Rickard, *loc. cit.*). Mr. Pittman, in his paper already referred to, brings evidence to prove that the Broken Hill silver lode is "a huge saddle lode formed in a fissure which owed its shape to the contortions which the gneissic rocks have undergone," and he illustrates his opinion by a diagram of which Fig. 56 is a reproduction. This opinion is supported and emphasised in the very able monograph on this district that has been prepared by Mr. Jaquet.[1] According to him the rocks of the district consist chiefly of slates, schists, and gneisses of possibly Silurian age or still



A.—*Cap of so-called intrusion.*

Fig. 56.—Diagrammatic section across Broken Hill Lode.

older; these have been thrown into numerous flexures, their strike varying between north-east and north-west, whilst numerous intrusive rocks are associated with them. The trend of the lodes coincides with the strike of the rocks; their walls show no flucan, no slickensides are visible, and in fact there is entire absence of any evidence that might show either wall to be a plane of shearing; in many places the country rock has been impregnated or more or less replaced by ore, and then no definite wall is to be found. There have moreover been extensive movements of the strata, subsequent apparently to the original plication, but

[1] J. B. Jaquet, "Geology of the Broken Hill Lode and Barrier Ranges Mineral Field, New South Wales," *Memoirs of the Geological Survey of New South Wales*, No. 5, 1894.

previous to the deposit of the ore. Mr. Jaquet is of opinion that the ore contained in the lodes is the result of lateral secretion, it "having been carried in solution from the country rock, through which it was sparsely scattered, and slowly deposited in its present position." Without in any way wishing to controvert this opinion, it is proper to observe that the phenomena described by Mr. Jaquet would lend themselves equally well to an explanation by the ascensionist theory, and that on either hypothesis it would be proper to look rather to the eruptive than to the sedimentary rocks for the origin of the metalliferous minerals. The primary ore of this deposit seems to be an intimate mixture of moderately fine-grained argentiferous galena and zinc blende, with a gangue of quartz, garnets, and felspar; iron and copper pyrites and a few other minerals also occur. The following is a complete analysis of a sample by Mr. J. C. H. Mingage, quoted by Jaquet (*op. cit.* p. 87):—

Moisture	2·065
Iron	5·675
Lead	18·755
Zinc	28·251
Copper	0·244
Arsenic	0·057
Antimony	trace.
Cadmium	strong trace.
Bismuth	nil.
Silver (30 oz. 4 dwt. 8 gr. per ton)	0·0925
Gold (0 oz. 3 dwt. 6 gr. per ton)	trace.
Alumina	2·161
Lime	nil.
Magnesia	2·399
Sulphur	20·426
Carbonic acid	0·350
Gangue (insoluble in acids)	18·500
Soluble salts (alkaline sulphates and chlorides)	0·510
	99·4855

A layer of secondary sulphide ore, so-called "sooty sulphide ore," consisting of the primary ore partly altered and enriched, coats the latter for a thickness of from three inches to three feet, whilst the upper part of the lode consists of oxidised ores of very varying description, chiefly carbonate of lead with sulphate and phosphate, carbonate of zinc, oxides of iron and manganese, native copper, carbonate and oxide of copper, and native silver and haloid compounds of silver, principally horn silver. These oxidised ores are evidently a true gossan formed by the action of surface waters upon the original sulphide ore. The accompanying section (Fig. 57), through the Jamieson shaft on Block 12, Broken Hill

Proprietary Company, which is one of many that accompany Mr. Jaquet's report, will serve to give a good idea not only of the shape of the deposit but of the mode of distribution of the various ores at that particular part of the lode.

Group *c*. Contact Veins.—Contact veins are metalliferous veins deposited at the planes of contact of two dissimilar rocks, when the dissimilarity has played a definite part in the genetic

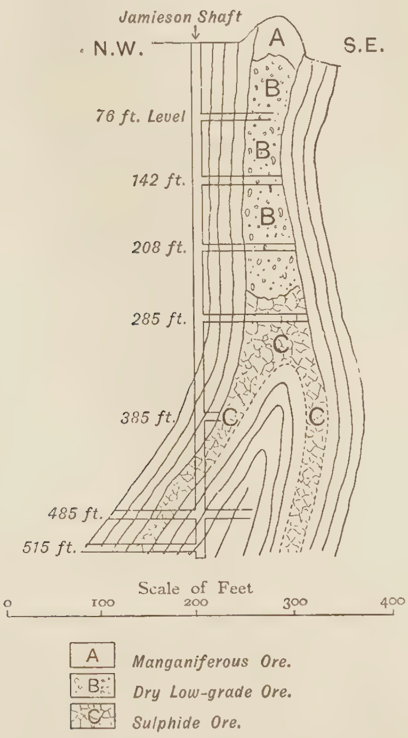


Fig. 57.—Section through the Jamieson shaft, Broken Hill Lode.

relations of the ore deposit—in other words when the deposit could not have occupied the place it does were it not for such dissimilarity. This class passes on the one hand into that of bedded veins, inasmuch as they are parallel to the stratification when they occur between stratified rocks, and on the other into that of irregular deposits when it happens, as it often does, that ore has been deposited in rounded or irregular masses, which may be more or less lenticular in form, in spaces which have been formed at the junction of two different rocks. When a series of such lenticular deposits follows such a plane of junction, it becomes a very open question under which head the deposit should be classed, nor is it perhaps a matter of great importance. Contact veins generally occur at the junction of eruptive and stratified rocks or at the junction of shales, sandstones, &c., with limestone; in either case mineralising solutions will have found their way along the plane of weakness existing at the contact, and have deposited metalliferous minerals, either in spaces previously eroded, or else by metasomatic interchange with the soluble or decomposable portions of one or other of the rocks.

Obviously a fissure vein occupying a fault, the throw of which is very great, may have its two walls composed of perfectly dissimilar stratified rocks of different geological ages, or may, by the same means, have one wall consisting of stratified and the other of eruptive rocks, or again may run between two eruptive rocks of different kinds and different ages. Such a phenomenon would not however warrant us in classing the deposit as a contact vein for the reasons already set forth, although it is proper to observe that, in the last case especially, it would be very difficult to distinguish to which class the deposit really belongs. No conclusion could then safely be arrived at without a thorough study of the geology of the entire district, although this is a case where the distinction would have an immense practical importance as throwing great light upon the probable permanence of the deposit.

When strata have been uplifted and have become metamorphosed through the agency of a central intrusive mass, an irregular band of metalliferous ore will sometimes be found extending along the line of contact between the eruptive and altered rocks, while in other cases it may be met with at some inconsiderable distance from the line of junction, with which, however, it preserves a general parallelism. Fig. 58 represents an ideal section of a line of contact between a stratified and an igneous rock, in the immediate vicinity of which occur the metalliferous deposits *a*.

Some remarkable deposits of this character are met with near Framont in the Vosges, where masses of specular iron ore surround a central boss of quartz-porphyry, which has tilted the stratified rocks, and specular ore has been introduced into all the resulting fissures and cavities, which are frequently lined with beautiful crystals of that mineral. The sheets and strings of copper which are concentrated at the junction of trap and sandstone at some points on the south shore of Lake Superior, afford an example of the deposit of a native metal along the contact planes of two dissimilar rocks. The copper ores of Monte Catini, in Tuscany, also belong to this class of deposit, being developed along the line of outcrop of certain gabbros, which Burat appears to regard as resulting from the metamorphic action of serpentine upon strata of cretaceous age.

One of the most typical of contact veins is the series of deposits at Leadville, Colorado. This has been very thoroughly described by S. F. Emmons,[1] and more recently again by A. A. Blow[2]; both these authors agree in describing the deposits as following the contact planes of eruptive porphyry dykes that have broken into at a low angle, and have in part overlain a bed of dolomitic limestone. At the plane of contact of the igneous rocks and the limestone, the latter has been shattered, and mineralising solutions finding their way along these planes, deposited the rich

FIG. 58—Contact deposits.

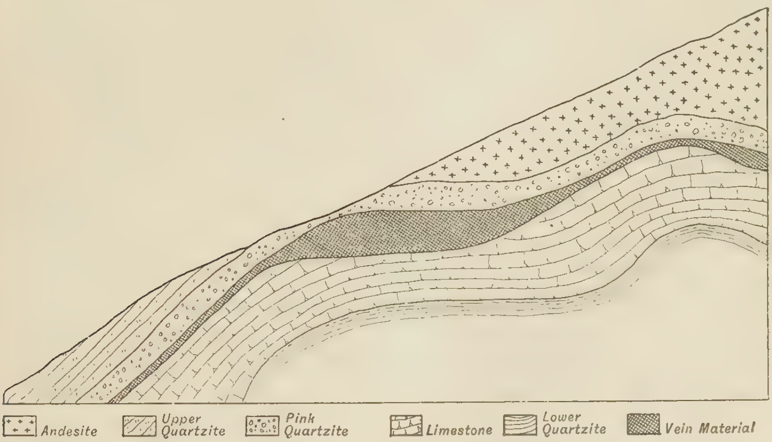
silver-lead ores by metasomatic interchange between the minerals carried in solution and the constituents of the limestone. So far both writers are practically in accord, and the above summary fairly represents their views, but they differ diametrically as to the probable source of the metals, Emmons holding that the solution reached the present locus of the deposit from above not from below, the neighbouring eruptive rocks appearing to be the immediate source whence the solution derived its metallic constituents. Blow on the other hand says that the ore deposits were formed by the action of hot alkaline mineral-bearing solutions coming from below, or by metal-bearing waters and vapours from solfataric action following the ejection of the porphyries and consequent thereupon, these ascending solutions penetrating

[1] S. F. Emmons, *Geology and Mining Industry of Leadville, Colorado. Ibid.* "The Genesis of Certain Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, 1886, xv. p. 125.

[2] A. A. Blow, "The Geology and Ore Deposits of Iron Hill, Leadville, Colorado," *Trans. Amer. Inst. Min. Eng.*, 1889, xviii. p. 145.

the limestone more readily along the planes of contact of the igneous and sedimentary deposits and within the zones of disturbance in which the limestone was crushed and broken (*see* page 134). Whichever therefore of these two views be really the correct one is a question that affects only the remote origin of the metallic ores, and not at all the proximate genetic conditions of the deposit which may be looked upon as pretty well settled.

A very similar deposit in Ouray County, Colorado, has been described under the title of the bedded ore deposits of Red Mountain ;[1]



Horizontal and Vertical Scales: 300 feet to 1 inch.

FIG. 59.—Section of ore deposit at Red Mountain, Colorado.

the ores as far as known seem to consist of auriferous and argentiferous oxidised lead ores occurring between a lower bed of white crystalline limestone and a thin upper bed of a light red argillaceous quartzite, which is in turn overlain by eruptive andesite ; there seems to have been hardly enough work done yet to be able to pronounce very positively, but from the description given and the section appended, of which Fig. 59 is a copy, this would appear to be a well-marked example of a contact vein. The association with it of fissure veins carrying similar ores, together with the general character of the deposit, prevents the acceptance of the hypothesis that this is an altered bed.

Pošepny describes several similar deposits in Eastern Europe, notably at Rodna in north-east Transylvania, at which place ores

[1] G. E. Redzie, "The Bedded Ore Deposits of Red Mountain Mining District, Ouray County, Colorado," *Trans. Amer. Inst. Min. Eng.*, xvi. 1888, p. 570.

consisting of pyrites, zinc blende, and argentiferous galena, slightly auriferous, in a gangue of quartz and calcite, occur in a layer (Pošepny calls it an "ore-bed," though this must be a mistake) of very variable thickness at the contact of limestone and andesite. A similar deposit is described by him as occurring at Offenbanya at a contact plane between mica-slate and overlying limestone; it seems to be connected in some way with an eruptive mass of andesite at the contact of which with the limestone there is another similar deposit, which may possibly unite with the first named.

It would also be feasible to include in this group some of the more tabular of the red hæmatite deposits of Cumberland, some of which might almost be described as veins. It will however be best to group all these hæmatite deposits together in the class of irregular deposits. The same remark may also be applied to the pyrites deposits of Huelva. The difficulty of dealing with these and similar cases is due not only to the fact that there is no such thing as a straight line in nature, and that natural phenomena refuse to fit exactly into the columns of our tables, but also to the transition stage through which the classification of ore deposits is at the present time passing. Obviously these deposits will be grouped in one or the other class according as genetic or morphological considerations prevail in the mind of the classifier. Under the compromise system, unsatisfactory like all compromises must be, which has been provisionally adopted here, such difficulties necessarily attain their greatest developments.

Group *d*. Gash Veins.—This is a somewhat unsatisfactory group, which is maintained here more because it has entered into the scheme of most previous classifications than for any other reason; it should probably be considered a special case of irregular deposits formed in cavities eroded in limestone which cavities have assumed a more or less tabular form whilst their position is approximately vertical.

Gash veins may be defined as metalliferous deposits which occur in limestone rocks only, and, being confined to a single stratum or formation, are necessarily limited in extent. The most typical examples of gash veins are probably those furnished by the lead deposits of the Mississippi Valley, in North America. These occur at three different horizons, of which the Galena Limestone, belonging to the Trenton Group, is the most productive. The origin of the cavities in which deposits belonging to this class have been formed, appears to be capable of a simple explanation.

They are generally the bedding planes or joints of a limestone rock which have become channels through which surface waters charged with carbonic acid have flowed into a system of subterranean drainage. These joints are, generally speaking, approximately at right angles to one another, and while some are vertical others are horizontal. In the formation of gash veins one or both members of a set of crossed vertical joints become enlarged into lenticular cavities or *gashes;* but it not unfrequently happens that the action of water containing carbonic acid not only results in the formation of vertical or horizontal galleries of moderate dimensions, but also of irregular pockets, some of which may occasionally be of considerable extent. These cavities have subsequently become filled with calcite, or sulphides of lead, zinc, and iron, originally disseminated through the surrounding or overlying country, but

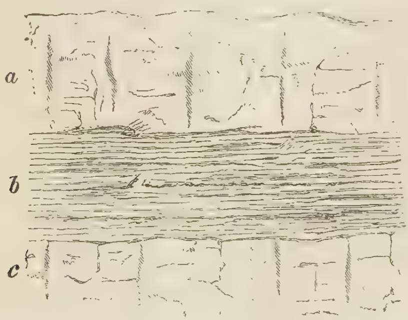


Fig. 60.—Gash veins; after Whitney.

which were afterwards leached out and deposited in the enlarged lines of jointing of the rock. In some instances these cavities have become further enlarged subsequently to the formation of a deposit of ore in them; and in such cases the ore may either form a central pillar, a sort of curtain depending from the roof, or be found as a mass of fragments mingled with sand and clay lying at the bottom of the cavity. The Carboniferous Limestone of South-western Missouri contains layers of chert which, not being soluble in carbonic acid, sometimes forms, where the limestone beneath it has been removed by the action of acidulous waters, either a ceiling to a cavity or a sort of diaphragm across it. These frequently break down with their own weight; and, falling to the bottom, the fragments become cemented together with the ore, which thus acquires a peculiar and brecciated character.

Fig. 60 represents an ideal section of one of the usual modes of occurrence of gash veins in the Mississippi Valley.

The stratum *b* lying between *a* and *c* entirely cuts off the veins, the fissures not having penetrated into that bed. Should the bed *c* resemble in its characteristics that which is marked *a*, similar fissures may be again found in it below *b*. In that case they will not however be continuations of the fissures found in *a*, but will, on the contrary, be a new set, originating and entirely comprised within the bed *c*. In connection with the main fissures, which may or may not be nearly vertical, lateral branches will usually be found in the same rocks, possessing similar characters with regard to their metalliferous contents.

In connection with ordinary gash veins there are usually deposits of lead ore in *flats* or *sheets*. This ore is sometimes accompanied by veinstone, and is unmixed with clay. The sheets vary much in their dimensions, but are generally elongated in one direction, and thin out gradually from the centre. Several such sheets are sometimes connected by vertical or oblique fissures containing ore, as represented in Fig. 61, descending by

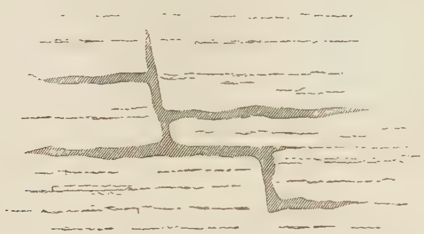


Fig. 61.—Lead ore in flats; after Whitney.

zigzags from one stratum to another. The principal veinstone associated with galena is calcite, with occasionally a little heavy spar. Sheets of these minerals alternate with others of calamine, blende, and iron pyrites. In some places the latter minerals are more abundant than galena itself, and calamine not unfrequently becomes the predominating mineral. Casts of fossils are sometimes found in the galena from the deposits of the Mississippi Valley.

These deposits have recently been made the subject of careful study by several American geologists. One of them, Dr. Jenney, announces a general law to the effect that "all workable deposits of ore occur in direct association with faulting fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore." He describes most of the deposits as "runs," these being irregular ore bodies formed at the intersection of an ore horizon with a vertical fissure; the roof and floor of the deposit are formed by the unmineralised beds which bound the favourable rock stratum above and below, its width is determined by the extent to which the rock was shattered so as to admit the mineralising solution, and longitudinally it stretches the length of the section of the fissure which remained open during the formation of the ore. Dr. Jenney is a strong ascensionist, and concludes his report thus[1]: "The only theory which, in all observed instances, will account for the occurrence of the deposits of lead and zinc ores and the associated minerals in the Upper and Lower Mississippi region is that of ascension, the source of the metals existing deep in the primitive rocks. With the discovery that the ore-bearing crevices are faulting planes of indefinite vertical extension, the classification of the deposits of the Mississippi Valley as the fillings of 'gash veins,' or crevices formed by the contraction or shrinkage of the rocks, and confined to a narrow vertical range within the geological horizon, must be abandoned."

Mr. A. Winslow,[2] who has investigated the very similar deposits of the State of Missouri, is an equally decided lateral secretionist; according to him the ore bodies are massive, lenticular, tabular, and cylindrical in form; he looks upon them as deposits filling crevices produced by the action of waters charged with carbonic acid and probably also organic acids, which sank into the rock along lines of fracture of jointing or of shrinkage. "The fact, that crevices diminish in width and die out with depth, is proof of their formation largely through surface agencies." The mineral is supposed by this author to have been originally diffused through the country rock and subsequently concentrated through surface-decomposition of the latter, supplemented by percolation. It is noteworthy that the latter writer never even refers to the term "gash vein" in his report.

When so much doubt is thrown, by those who know them best, upon the nature of the deposits in the typical gash vein region, it may well be doubted whether the group deserves separate recognition, except as a matter of temporary convenience.

The *pipe veins* of the north of England very closely resemble gash veins, and were probably formed in the same way, as were also many of the hæmatite deposits in the Carboniferous Limestone.

1 Walter P. Jenney, "The Lead and Zinc Deposits of the Mississippi Valley," *Trans. Amer. Inst. Min. Eng.*, xxii. 1893, p. 171.

2 Arthur Winslow, "Lead and Zinc Deposits of Missouri," *Trans. Amer. Inst. Min. Eng.*, xxiv. 1894, p. 634.

It is highly probable that the metasomatism has played a more important part than is generally admitted in the formation of all the above deposits.

SUB-CLASS II. MASSES.

The deposits included in this sub-class are distinguished from those of the preceding classes by the well-marked morphological characteristic, that whereas these latter are more or less tabular in form, the former are bodies of no definite shape, and of lesser extension. Sometimes these deposits are very large indeed, but in such cases they are usually, roughly speaking, ellipsoidal or lenticular, having a considerable magnitude in each of their three dimensions. The lenticular form is a very common one, and as already pointed out, a series of lenticular deposits may be looked upon and treated as a bedded deposit showing extreme variations in thickness. The deposits of this class have received many names, the larger ones being known as chambers or pockets and the smaller ones as bunches, blows, nests, &c. The Germans have used a still larger variety of names, the larger ones being known as *Stöcke*, and the smaller as *Butzen*, *Nester*, *Nieren*, &c. So many of these names, which refer usually to the shape or dimensions of the deposits, have a merely local application, whilst their employment might necessitate calling a number of deposits, produced in quite the same way and differing only in shape or dimensions, by different names, that it has appeared simpler to discard them all, and to speak of them simply as masses or massive deposits; it will be seen that this class might again be sub-divided according as the whole massive deposit consists of ore (intermixed nevertheless with some gangue), or as it consists of an irregular mass of igneous rock impregnated with metalliferous particles. If this classification were employed, groups *a* and *d* would belong to the latter and *b* and *c* to the former, but as each group is individually pretty well characterised, it has not been thought advisable to insist on such sub-division.

Whenever the strata in which a massive deposit is enclosed have been faulted subsequent to the formation of the deposit, it naturally partakes of the movement of its wall rocks, so that what has been previously said of the faulting of beds and veins applies equally to massive deposits when these happen to be traversed by a fault plane.

GROUP *a*. STOCKWORKS.—This name is given to a large and indefinite group of irregular mineral deposits, whose main characteristics are the following: the mass consists of either igneous, metamorphic, or stratified rock, which is impregnated with metalliferous mineral, either in the form of small reticulated veinlets or more or less uniformly disseminated through the rock in connection with veins; the mass is irregular in outline, and does not possess any sharply-defined limits, merging gradually into the surrounding rock, the walls of the deposit being accordingly fixed by purely technical considerations, not by geological distinctions. This group has accordingly affinities with fissure veins, especially such as have been produced by metasomatic action, and with the class of veins known as *mullock* veins in Australia; with the disseminations through beds of Class I. from which it differs chiefly in that the ore deposit in the latter case has definite boundaries, namely, the floor and roof of the bed, the entire bed being in that case ore bearing; and with some varieties of metasomatic masses, from which it is distinguished chiefly by the respective dimensions of the actual pieces of ore, which may be very large indeed in the case of bunches and microscopic in the case of stockworks. The typical stockwork, a term that has been adopted both in this country and in France, taken from the German *Stockwerk*, consists of a mass of granitic rock traversed by a network of small veins interlacing with one another and traversing the rock in various directions; the whole of the ore present is not, however, confined to the veins, a considerable portion of it, on the contrary, being contained in the rock itself. These deposits are also known as *floors* or *carbonas* in this country, and as *Trümmerstöcke* in Germany. Typical examples are the tin deposits of Altenberg, Geyer, and Zinnwald in Saxony, and at the Carclaze, Beam, and Bunny Mines, in the neighbourhood of St. Austell, and at various other places in Cornwall.

At Carclaze the veins traversing the granite are generally small and vary considerably in composition; sometimes they consist of schorl and quartz, at others of schorl and felspar, frequently of schorl alone, and occasionally portions of them are composed of felspar only. They are usually, however, a mixture of the three minerals, and generally contain a certain proportion of tinstone. As in the case of other similar deposits, the ore is seldom confined to the veins alone but is generally dispersed throughout the mass of the contiguous rock, into which, although the line of separation is often distinguishable, the veins frequently pass by imperceptible gradations.

On the whole the veins preserve a certain amount of parallelism, but there are exceptions to this, and in such cases they frequently exhibit the ordinary phenomena of heaves and slides, and when such veins unite, they are often enlarged and become proportionately more productive. They are, however, generally so small and numerous and at the same time so intimately mixed up with the rock mass, that the mine has been for the most part worked open to the day, forming an excavation 250 fathoms in length, 100 fathoms in width, and about 22 fathoms in depth. These workings were formerly carried on upon an extensive scale, but of later years Carclaze has been worked chiefly for china clay, although a small quantity of tin ore is still collected during the operations. Beam is situated about two miles north of Carclaze, and was originally quarried, but was subsequently worked in the usual way by mining; Bunny resembles Beam in its usual characteristics, but is upon a considerably smaller scale.

Carbonas are very similar deposits which may occur either independently and alone or else associated with others of a more definite character, the latter being often the case in Cornwall. Thus according to W. J. Henwood,[1] at the St. Ives Consolidated Mines a carbona joins the Standard lode at a depth of 78 fathoms, and at its point of junction therewith the connecting surface is not above four or five inches square. From that point it has been worked for a distance of 120 fathoms in length, with a constant inclination downward, until it reaches a depth of nearly 100 fathoms. Its greatest vertical extent is nearly ten fathoms, and its extreme width about the same; but the average dimensions may be taken at four fathoms high by ten or twelve feet in width. It exhibits few of the usual characteristics of a lode, being bounded above, below, and on either side by ordinary granite. The deposit itself is chiefly composed of felspar, quartz, schorl, and oxide of tin, very irregularly distributed throughout the mass. In some places it contains in addition fluor spar, which is not present in the adjoining lode, chlorite, chalcopyrite, erubescite, and iron pyrites. Throughout this mass there is a gradual transition from the composition of granite to that of the carbona.

A section of this deposit is given in Fig. 68, page 207.

At Altenberg, in Saxony, the stanniferous rock, which is generally a porphyry of a grayish colour sometimes merging into *greisen*, a rock consisting of quartz and mica, forms a mass 1,400

[1] *Trans. Roy. Geol. Soc. of Cornwall*, v. 1843, p. 21.

feet in length, and 900 feet in width, surrounded by granite and different varieties of porphyry. This mass contains tin ore over its whole extent, but in such small quantities as to be almost imperceptible to the eye. It has a dark, often almost black colour, and consists of quartz, felspar, mica, specular iron ore, tin ore, and probably a little wolfram. Pyrites is sparingly disseminated throughout the rock, but the quartz, which occurs in a granular form without any apparent crystalline structure is often the only mineral that can be distinctly recognised. Numerous veins of quartz traverse this fine-grained metalliferous rock in all directions, in which molybdenite, bismuthine, copper pyrites, fluor spar, topaz, prehnite, and nacrite sometimes occur. The rock differs from ordinary greisen in that its texture is not quite the same, and in containing chlorite and specular iron ore. This rock, which is called by the miners *Zwitter* or *Stockwerks-porphyr*, is, as well as the neighbouring granite, traversed by numerous small and irregular veins of quartz, each of which is bordered, on both sides, by dark stripes. These dark stripes merge without any distinct line of junction into the finely granular granite; it would therefore seem as though the dark stripes were the result of impregnation by liquids traversing the vein fissure previous to its becoming filled by quartz. From analyses made at Freiberg it would appear that there is but little difference in the composition of the unaltered granite, the dark-coloured stripes bordering the quartz veins, and the zwitter.

At Geyer, the rock enclosing the numerous small string-like veins is a granite of which the felspar is much decomposed. This granite has broken through mica schist, and the associated minerals are schorl, fluor spar, oxide of tin, and apatite. Cassiterite is not only present in the small parallel veins, but is also disseminated through the adjacent rock. The veins rarely exceed two inches in width and gradually merge into the granite.

At Zinnwald, tin ore is obtained from a granitic rock sometimes classed as a greisen, containing but a very small proportion of felspar, and forming a flattened dome-shaped mass, which rises through a larger one of porphyry. The whole of this rock is frequently stanniferous, but the most productive deposits exist in the form of concentric zones, none of which exceed twelve inches in thickness. Seven of these zones or foliations, which Burat[1] regards as contemporaneous with the granite, and from which he believes they were separated by a sort of liquation, are of sufficient

[1] *Géologie Appliquée*, Paris, 1855, p. 339.

importance to allow of being worked for tin. Subsequently to its consolidation the mass of the granite has been faulted by various fissures, now filled with clay and other débris, so that the metalliferous zones have experienced numerous throws.

An excellent description of these deposits has lately been published by Dr. Karl Dalmer;[1] according to him a belt of eruptive rocks breaks through the Archæan sedimentary formation of the Erzgebirge in a north-west line, along which are a series of fissures and important faults. These eruptives may be classified as (*a*) quartz porphyry, the so-called *Tepltiz-porphyry ;* (*b*) granite porphyry, younger than the former ; and (*c*) a series of intrusive cones of granite, the most recent of the series. The tin deposits are closely connected with the last-named ; they take the form of "impregnation fissures," *i.e.*, fissures in the immediate neighbourhood of which, whether filled or empty, the country rock is changed into a *greisen*-like rock and is impregnated with tin-stone, the width of the zone so altered varying from a few inches to some yards. The existence of these impregnation fissures is closely connected with the granitic masses and the rocks in contact with them. In the granitic cones they are generally confined to the boundaries thereof with the older porphyry or with gneiss, so that an outer ore-bearing capping may be distinguished from the inner unaltered poor or barren rock that succeeds it in depth. This phenomenon is well marked at Altenberg, where a granite cone breaks through the granite porphyry ; the upper part of this cone is so completely traversed in every direction by a close network of impregnation fissures that the entire mass, except for some residual portions, has been altered to a stockwork of ore-bearing greisen (*Zwitter-gestein*), which extends to a depth of some 230 metres below the summit of the eruptive cone, at which point the undecomposed granite containing but a few narrow belts of impregnations makes its appearance.

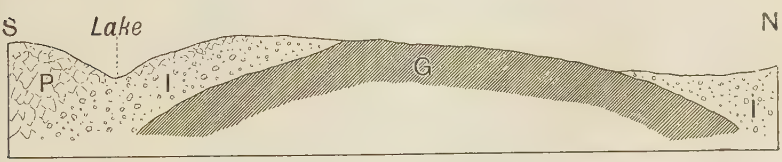
The smaller granitic cones of Graupen and Bärenstein are quite similar to the above. In the Zinnwald granitic cone the tin-stone gets poorer in depth, as shown in the section (Fig. 62). In the lowest adit, some 100 metres deep, there are only a few comparatively poor veins of tin, which are found close to the contact of the granite with the porphyry, and further in there is little except undecomposed granite. Near the Bohemian side, however, the stanniferous greisen is found to continue down below

[1] "Der Altenberg-Graupener Zinnerzlagerstätten-district," *Zeitsch f. Prakt. Geol.*, 1894, p. 313.

this level. In addition to the granitic stockwork, the tin stone impregnations extend in all cases into the surrounding porphyry and gneiss which are intersected by true tin veins and by belts of impregnation. A very regular zone surrounds the granitic stockwork of Zinnwald, as is well shown in the section (Fig. 62).

Dr. Dalmer explains these phenomena by adopting Daubrée's theory—the so-called "pneumatolytic" theory of the deposition of tin-stone by the action of ascending vapours of the fluoride, to which reference has already been made (p. 145). He supposes that the metallic vapours, ascending in the slowly solidifying granitic magma, attacked the upper portions of the granite which were the first to solidify, and at the same time penetrated the surrounding rocks; as solidification extended downwards, the mass, becoming pasty, no longer afforded a ready passage to these vapours, hence the lower part of the cone remained comparatively unacted on and free from tin.

This hypothesis is worthy of being put on record, but it can



Scale 1:30,000

G. granite (the shaded portion shows the limits of the tin-bearing rock; P. quartz-porphyry; I. its zone of impregnation.

The datum line is 400 metres above sea level.

FIG. 62.—Vertical section through the tin stock-work at Zinnwald; after Dalmer.

hardly be looked upon as thoroughly satisfactory or as explaining all the phenomena of these tin deposits. There seems no urgent reason for adopting the theory of pneumatolytic, in preference to ordinary hydrothermal action.

At the Polberrow Mines in the parish of St. Agnes, Cornwall, a pale blue slate of silky lustre is traversed by numerous small tin veins. This rock extends to Trevaunance, forming the sea-cliff between that place and Trevellas Coombe, and contains many small quartz veins in addition to several lodes and cross-courses. The way in which these tin veins occur in slate rock is well illustrated in Fig. 63, which represents a specimen from this locality, of which a lithograph is given by Henwood, in his valuable monograph on the Metalliferous Deposits of Cornwall and Devon. Writing in 1838, this author makes the following observations relative to the workings at Polberrow:—"In pursuit of these little tin veins the excavations have been so numerous and extensive, that a mass of rock extending from the surface to sixty fathoms deep, being unsupported, is now slowly subsiding. The portion thus in motion is perhaps sixty or eighty fathoms in diameter, and its descent at the rate of six or eight feet in a month. The miners still continue their labours in the moving mass." This appears to be the only stockwork ever extensively worked in clay slate, and it would be interesting to determine by means of analysis whether the whole of the oxide of tin is contained in the small veins, or whether a portion of it may not be enclosed in the slate itself.

The mode of formation of all these deposits is apparently

Fig. 63.—Tin veins in clay slate, Polberrow.

similar; the rock in which they occur has been shattered to a greater or lesser extent by eruptive action or by dynamic movements of the earth's crust, either definite, but small and irregular, cracks being formed through a certain zone, or a portion of the rocky mass being thoroughly crumbled by the pressure, this latter being more likely to occur in the case of a granular rock like granite than in that of a stratified rock. As a result of the shattering of the rock, it was rendered permeable to mineralising solutions, which partly deposited their freight of metalliferous mineral in the open interstices or cracks, and partly exchanged it for the more decomposable mineral constituents of the rock, thus forming impregnations by metasomatic interchange. The well-known beautiful pseudomorphs of tin-stone after felspar that have been found plentifully in several Cornish mines are good evidence of such metasomatic action, the chemical possibilities of which have already been discussed.

GROUP *b*. MASSIVE DEPOSITS IN CALCAREOUS ROCKS.—This again is a group ill-defined both in its genetic and its structural relations. It is difficult to say in some cases whether the mineral deposit has filled a pre-existing cavity or whether it has been formed metasomatically. The bulk of the evidence seems to declare that the latter form is far the more frequent, and that many deposits that have been referred to the former were really produced by the latter mode of action. This group ought probably to be made to include that of gash veins, with which some of the deposits at any rate have striking affinities, and, as already pointed out, it merges by very indefinite degrees into that portion of the group of contact veins in which one of the walls is limestone.

Obviously the present group must be taken to include such irregular deposits as, though not wholly in limestone, have been developed at the contact of limestone with other rocks and owe their existence to the ready solubility of the former.

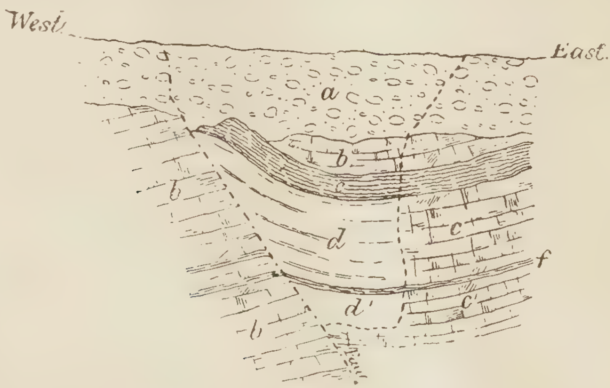
Typical deposits of this class are the Cumberland red hæmatite and the Forest of Dean brown hæmatite deposits, a whole series of zinc deposits in Belgium, in Spain, in Corinthia, and other localities, and various silver deposits in North America and other parts of the world. It seems highly probable that the recent discovery of Münster that carbonate of silver is freely soluble in water containing carbonic acid may in part explain the frequency with which silver ores are found filling cavities in limestone rocks.

The hæmatite deposits of Cumberland will be fully described further on; it need only be said here that they are almost confined to the limestones of the Lower Carboniferous formation, of which rock there are some seven[1] different belts comprised in the Yoredale rocks and the Mountain Limestone, these belts being separated usually by beds of shale, thin seams of which occur in some of the limestones. Deposits occur in all these beds of limestone, often at their upper or lower junctions with the shale beds, and occasionally connected with fault planes of more or less importance. Some of these faults are no doubt older than the deposits, and stand in direct genetic relation to them, but others have faulted both the beds and the deposits contained in them, and are therefore necessarily of younger date.

Mr. Kendall's explanation of the origin of these ores is probably the correct one; he considers them to have been formed by metasomatic replacement of the limestone by solutions of iron, the

[1] J. D. Kendall, *The Iron Ores of Great Britain*, 1893.

existence of which he connects with the volcanic agencies of which the district shows convincing evidence. He points out that Carboniferous fossils (chiefly brachiopods and corals) have been found partly or wholly converted into hæmatite, that pseudomorphs of hæmatite after calcite have been found at Parkside, and gives the section across an opencast working at Crossfield (Fig. 64), which is here reproduced. It will be noticed that the limestone originally contained a thin interbedded seam of shale *f*; when the ferriferous solutions which may possibly have come upwards through the fault fissure to the west of the deposit, attacked the limestone, producing hæmatite by metasomatic interchange, no such chemical reaction could take place with the shale, which therefore remained unaltered; for a similar reason the roof of the deposit consists of



Scale 40 feet to 1 inch.

a, boulder clay; *b*, limestone; *cc'*, limestone, very siliceous; *dd'*, red hæmatite; *e*, red and gray shale; *f*. gray shale.

The dotted lines show the sides of the open cut.

FIG. 64.—Section across the hæmatite deposit at Crossfield; after Kendall.

a hard siliceous limestone which was less readily attacked than the softer and purer limestone below it. It is obvious that this ore could not have been deposited in a pre-existing cavity, because such a thin layer of shale could not have maintained its unbroken continuity across a cavern during all the time that would have been required for it to be filled with the ore, whilst it is very doubtful whether a roof arching downwards, as in this case, could have stood without falling in for so long a period. Moreover the gradual passage from clean ore through red-stained limestone into comparatively pure limestone is best explained by the theory here adopted.

All the zinc deposits above mentioned present several points of similarity. In Belgium (*see* p. 360) the highly contorted Carboniferous limestone is traversed by a series of fissure planes whose general direction is N.N.W.—S.S.E., which, together with certain true fissure veins, are evidently connected with the irregular deposits of calamine; these latter are generally developed at the contact of the limestone with the strata immediately above and below it, and it seems pretty evident that these deposits have been formed by the metasomatic action of zinciferous solutions circulating in these fissures upon the limestone. This view is corroborated by the existence of fossils partly or wholly converted into calamine, as well as by the general characteristics of the deposits.

At Raibl in Corinthia a series of limestones and dolomites of Triassic age, overlain by schists, have been broken up by numerous fissures. Along these are found irregular deposits of calamine, which are often found to retain the characteristic cellular form of the calcareous rocks. Similar deposits again occur at Carthagena and at Santander, the former in rocks of Permian, the latter in rocks of Cretaceous or Post-cretaceous age. The geological horizon of these deposits is therefore very variable, whilst their general characteristics are uniformly similar, pointing in each case to identical modes of origin. It is in many cases doubtful whether the calamine was deposited as such, or whether it is an alteration product of zinc blende.

A number of extensive and important deposits of silver ores in limestone rocks are known in the United States, such as the Eureka Consolidated and Richmond mines in Nevada, the Emma, Flagstaff, and Kessler Cave Mines in Utah, &c. These may have been produced metasomatically, like the previously described deposits, and this theory would no doubt explain all the observed phenomena.

Dr. Newberry, however, believes that the erosion of the spaces within which the ores occur was long antecedent to the deposition of the ores, his explanation being as follows :—

A stratum of limestone more than usually soluble in atmospheric waters containing carbonic acid, has at some period been honeycombed into chambers and galleries, such as those which traverse the limestone plateau of Central Kentucky, of which the Mammoth Cave is a well-known example. Subsequently the rock was broken through and uplifted by the subterranean forces which have disturbed all important mining districts, and through the fissures thus formed, mineral solutions ascended and flowed into any cavity that might be open to receive them. Whenever these fissures traverse an insoluble rock, they have become fissure veins, whereas, when cavernous limestone was broken into, its open galleries and caverns were more or less completely filled with ore. It has been suggested that the caves now holding these ores may have been produced by the action of the same metalliferous solutions from which the ores were deposited. This, however, he does not think probable, since many of the cavities are without ore and have their sides incrusted with crystals of calcite ; and even where ore is met with, the surrounding walls are always hard and unimpregnated with ore. He concludes therefore that the chambers were formed, like modern caves, by surface waters, and that at the time the country was uplifted and the rock shattered some of them only were broken into ; these alone received the metalliferous solutions and ultimately became, at least partially, filled with ore, while those which were not in communication with the metalliferous channels have remained empty. The character of the ores contained in these chambers varies as much as it does in ordinary fissure veins, thus showing that the nature of the metalliferous solutions was not always the same in different localities. There can be no doubt that argentiferous galena was the ore most abundantly deposited in these chambers, but in some cases it was associated with large quantities of iron pyrites, while in others this mineral is almost entirely absent.

The ratio of gold to silver varies greatly in such ores ; those of the Eureka Mine are rich in lead, and contain much iron, while the aggregate value of the precious metals is about £14 per ton, of which one half is represented by gold and the other half by silver. The ores of the Emma Mine were richer in lead, and contained less iron and a little copper, but much more silver and less gold. Similar differences occur in all the chamber mines, but in every instance the ore has become thoroughly oxidised. In some of the neighbouring fissure veins, however, the decomposed ores of the chambers are represented by unaltered masses of galena and iron pyrites, in which forms the ores were doubtless originally deposited in the caverns of the limestone ; in such veins the galena usually carries the silver, and the pyrites the gold. The enormous production of silver and gold from the chamber mines already worked in the United States sufficiently demonstrates the great importance of this class of deposit, but should the theory suggested by Dr. Newberry be correct, they cannot be expected to extend to such great depths as the ore-bodies of fissure veins ; since the excavation of the limestone if produced by meteoric water, cannot extend beyond the zone traversed by surface drainage.

It will be seen that the above theory really demands that the rocks shall have been traversed by two entirely different systems of water circulation, the first an unsaturated one of probably vadose waters containing sufficient carbonic acid gas to dissolve the limestone, and the second a solution containing so much metallic matter in solution as to be able to deposit sufficient to fill the caverns with ore; it also demands that the forces which shattered and uplifted the rocks shall have done so without crushing in the caverns, and it is hardly clear how, after being near enough to the surface to be thus eroded, the bed came to be, after farther upheaval, at a sufficient depth for the cavities to be filled with mineral, there being no evidence to suggest that this deposition of ore took place near the surface of the earth's crust. It would seem therefore a simpler explanation to consider these deposits as having been formed metasomatically by the action of solutions that circulated through the fissures referred to by Dr. Newberry, the difference between this theory and his being that solution of the limestone and deposition of the ore by the former hypothesis are supposed to have gone on simultaneously, and not in successive stages separated by a wide interval of time.

A form of deposit allied to this class is that of the bunches, pipes and flats of lead and zinc ores, generally the former, that are often found to accompany veins of these minerals. They are not uncommon both in the north of England and in the Derbyshire lead-mining districts, being in both nearly or quite confined to the limestone strata traversed by these veins. These deposits seem to be closely allied genetically and even to some extent morphologically to gash veins, and seem to have been formed by deposition in pre-existing cavities.

Group *c*. Masses in Igneous Rocks.—A very large and important series of mineral deposits occurs in the form of irregular masses, often of a more or less lenticular shape, either in igneous rocks, or closely connected with these latter, sometimes at the plane of contact of the igneous rock with an older one; in this last case, as already pointed out, they present marked analogies with contact veins from which they can only be differentiated by their form being lenticular rather than tabular. These deposits have been recently studied very exhaustively by J. H. L. Vogt,[1]

[1] J. H. L. Vogt, "Bildung v. Erzlagerstätten durch Differentiations-processe in basischen Eruptivmagmata," *Zeitsch. f. Prakt. Geologie*, 1893, p. 4, &c.;

N 2

who considers that most of them have been formed by "magmatic differentiation" from the igneous rock, whilst the latter was still in a semi-fluid or plastic condition. The chief deposits of this class are deposits of oxidised ores such as magnetite, ilmenite, &c., and of sulphuretted ores, mainly iron pyrites, either cupriferous or nickeliferous, or both.

It is very doubtful how far Vogt's generalisations respecting the sulphide ore deposits are admissible. In the first place it has never yet been shown that iron pyrites is capable of fusion without decomposition; it is well known that it is decomposed when heated to moderate redness in closed vessels, but certain experiments upon its formation that have been recorded by Dr. Percy,[1] would seem to warrant the inference that it may resist a higher temperature if heated in sulphur vapour and therefore if heated under great pressure. It may in either case be considered certain that the melting-point of this compound, or of any other of the metallic sulphides found associated with it, must be considerably lower than that of an ordinary eruptive rock, and that any sulphides contained in it must accordingly have retained their liquid form long after the rock itself had become solid, and have therefore crystallised or solidified in the interstices between the mineral constituents of the rock. This, however, is by no means the position in which these sulphide ores are found. It is known with certainty that iron pyrites and the sulphides that accompany it in these deposits can be produced by precipitation from solution and have been thus formed in mineral veins. It would accordingly seem preferable to refer the genesis of all these sulphide deposits to hydrothermal action and to look upon them as having been introduced into the sites they now occupy in the form of solutions; they may have percolated through shrinkage cracks or into cavities formed by shrinkage either in the mass of the solidified igneous rock or between it and the stratified rocks through which it penetrated, and the solutions would in all probability not only fill the cavities but also attack their walls, depositing metallic minerals, or dissolving the non-metallic rock-forming mineral, just as in the analogous case of fissure veins. The wider question whether or not the ores were brought up in a fused state disseminated through the igneous rocks hardly admits of a positive solution as yet,

"Beiträge zur genetischen Classification," &c. *Zeit. f. Prakt. Geol.* 1894, p. 381; "Über die Kieslagerstätten vom Typus Röros," &c. *Z. f. Prakt. Geol.* 1894, p. 41, &c.

[1] John Percy, *Iron and Steel*, 1864, p. 41.

although a good deal of evidence has been accumulated that seems to point to an ultimate answer in the affirmative. The connection between igneous eruption and sulphuretted vapours and sulphur deposition is, however, too constant to be overlooked.

With regard to oxidised ore deposits the case is somewhat different, many oxidised ores, magnetite, for instance, being known to be fusible as such, and to occur plentifully in certain eruptive rocks, as apparently original integral constituents thereof. The large magnetite deposits in granitic and gneissose rocks of Scandinavia, the United States, &c., may have been segregated out from these rocks whilst the latter were in such a condition of semi-fluidity as to admit of their particles rearranging themselves freely. The rocks need not have been absolutely molten for this action to be possible; their crystalline structure is indeed sufficient proof that their particles possessed such freedom of movement, which was no doubt largely aided by the presence of aqueous vapour under high tension. The magnetic properties of the ore would be sufficient reason why the metallic particles should tend to cohere and thus segregate out of the magma. At the same time it is quite possible that these ores, like the sulphuretted ores, were in a state of solution and owe their origin to some chemical action—a reducing action perhaps upon salts of iron, either at high or at low temperatures.

According to some authorities they were originally deposited among the stratified rocks either as brown hæmatites (compare the origin of lake and bog ores), or as carbonates, and were altered to magnetite by the same metamorphic action that altered the strata enclosing them. It is clear that if this last theory or if that of Vogt be adopted, this group of deposits should strictly be classed as symphytic instead of epactic. In view, however, of the uncertainty as to their origin which still prevails, their structural analogies with other irregular deposits, and the fact that they may be viewed broadly in relation to the surrounding stratified rocks which were obviously formed before the igneous rocks with which these deposits are connected, and which would in this sense be older than the deposits, it has been thought best to retain this group in the position it here occupied in close conformity with the arrangement of previous classifications.

As a typical example of the oxidised deposits, the well-known deposit of magnetite at Dannemora in Sweden can be quoted; it consists of a series of lenticular masses of ore, the largest of which is 50 metres wide and 200 metres deep; these masses are contained in a narrow belt of limestone running from north-east to south-west. This latter rock is intercalated between masses of *hälleflinta*, a gray porphyritic quartz rock, which in places forms the actual wall of the deposit; all the surrounding rocks are highly metamorphosed, consisting largely of granite and gneiss. The origin of the magnetite deposits seems to be closely connected with the existence of the igneous and metamorphic rocks of the district, although their exact genetic relations have not been determined. Other Scandinavian deposits, such as those of Norberg in Sweden and of Gellivara in Norway, consisting of magnetites and hæmatites in metamorphic rocks closely associated with various igneous ones, may also be included in this class.

On the west shore of Lake Champlain in Northern New York State there are a number of deposits of magnetite of a more or less lenticular form, the enclosing rocks being gneiss or granite. These mines are all in the neighbourhood of Port Henry, the largest being the so-called Old Bed Mines; these were first worked as apatite deposits, consisting at the surface of granular apatite with which a good deal of magnetic iron ore was intermixed, the latter having to be separated out. In depth the amount of apatite decreased so rapidly that the deposit has admitted of being worked for many years as a Bessemer ore. The chief deposit is over 200 feet thick and 1,500 feet long. There are a number of thinner deposits that either resemble or are true veins more or less parallel with the bigger deposits, in which the ore is free from apatite, but is associated with a good deal of quartzose gangue. The strike of these vein-like deposits is about north—south, and they dip at about 40°. It is noteworthy that none of these deposits have any true walls, the ore passing gradually into the country rock through various stages of poor ores. The country rock, even at considerable distances from the deposits, contains disseminated magnetite. It is upon the whole highly probable that these deposits have been formed by magmatic segregation.

According to Vogt[1] deposits of chromite all over the world are basic magmatic segregations from peridotite, occurring as lenticular masses of varying dimensions in peridotite or in serpentine resulting from the alteration of that rock. The proportion of Cr_2O_3 in the actual rock is about 0·2 to 0·35 per cent., and it bears no relation to the degree of serpentinisation of the rock, which shows a gradual passage from peridotite to chromite through stages characterised by varying amounts of Cr_2O_3.

[1] *Op. cit.* 1894, p. 381.

There are numerous excellent examples of massive deposits of sulphuretted ores either in or associated with igneous rocks; amongst these may be mentioned the big deposits at Rammelsberg, various Scandinavian deposits, the important deposits of Huelva on the boundary between Spain and Portugal, Sudbury in Canada, and many others.

At Rammelsberg an irregular rather flattened lenticular mass of ore with a curious lateral offshoot has been worked for some 900 years, the deposit being 1,100 to 1,200 metres long and 15 to 20 metres wide; its structure is shown by the section (Fig. 65) taken from Vogt's paper. It lies between inverted Goslar slates

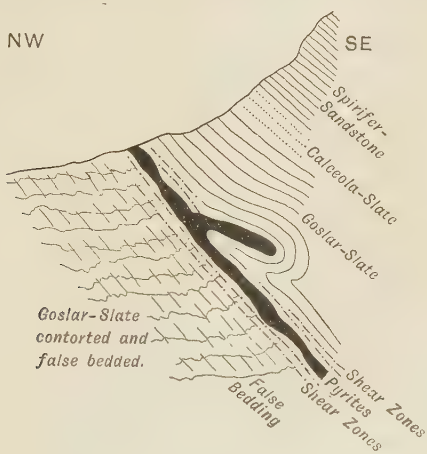


FIG. 65.—Ideal section of the pyrites deposit at Rammelsberg; after Vogt.

(base of the Upper Devonian) on the hanging wall and the same slates occupying their normal position on the foot wall side, occupying the centre of a broad "shear-zone" or series of faulting planes; its formation is closely connected with certain lines of eruption of granite in the immediate neighbourhood, and the presence of the ore may be due to the eruption of these rocks by which the ores were brought in, as Vogt believes, or else they were deposited in the spaces formed in the above shear-zone from metalliferous solutions.

Whichever theory be the correct one the facts of the deposit seem to be fairly well ascertained, and it is interesting to compare the section here reproduced with the older ones on pages 392 and 393.

Of the Norwegian deposits that at Varaldsö may be taken as the type. As shown in Fig. 66 this mine is working on several narrow lenticular deposits that have a vein-like extension, and often approximate to linear dimensions like pipe veins. They are imbedded in Cambrio-Silurian metamorphic schists, to the bedding of which they are parallel; the deposits at times pass gradually into the surrounding country rock instead of showing definite walls, and the rocks are traversed by shear-zones. This deposit, like all other Norwegian deposits, is accompanied by a well-marked development of sassurite gabbros, with the presence of which the existence of the deposit seems to be intimately connected.

The deposits of cupriferous iron pyrites in the Spanish province

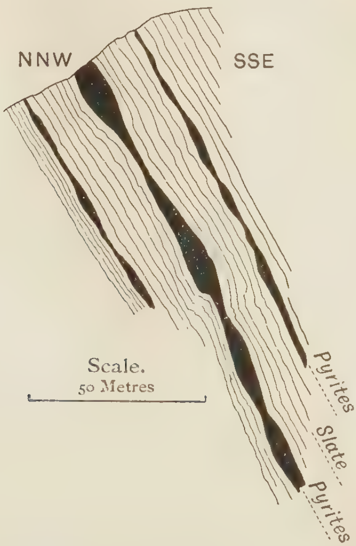
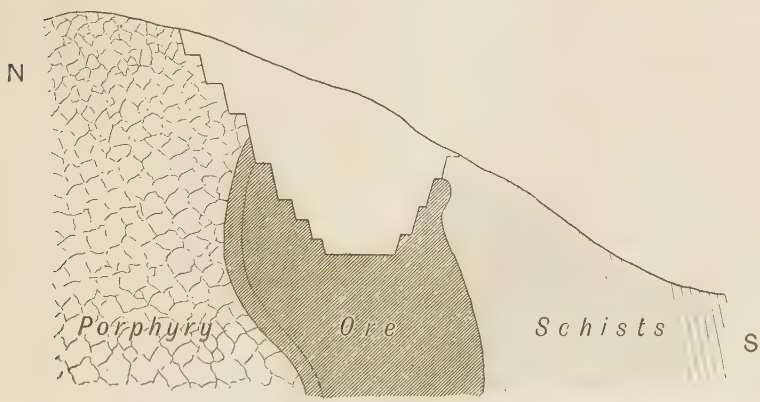


Fig. 66.—Section through the pyrites deposit at Varaldsö; after Vogt.

of Huelva and in the neighbouring district of Portugal are of very great importance. The largest deposits are those of Rio Tinto, the so-called north vein being 2,000 metres long and 150 metres wide, and the so-called south vein 550 metres long by 120 wide; the depth to which they have been worked is some 160 metres. Other important deposits are those of Tharsis, San Domingo, Lagunazo, &c. As shown by Fig. 67, a section across the south vein of Rio Tinto after de Launay, the ore occurs in irregular lenticular masses intercalated between a porphyry dyke and Carboniferous schists. The ore consists of iron pyrites with small quantities of other minerals, galena, zinc blende, chalcopyrite, &c.,

carrying about 2·5 per cent. of copper, together with a small proportion of silver and traces of gold.

GROUP *d*. DISSEMINATIONS IN IGNEOUS ROCKS.—This is a small and ill-defined group, in which may be included deposits that resemble stockworks, but show no definite veins; deposits like those of the last group in which each individual mass is so small as not to be workable separately, but to necessitate the entire mass being worked; deposits related to group *c* of the symphytic deposits in which an igneous and not a stratified rock has been impregnated by some metallic mineral; and igneous rocks from which a metallic constituent has separated out in small particles by segregation. These deposits have been sometimes described as *impregnations*, but the term here used seems



Scale $\frac{1}{5000}$

FIG. 67.—Cross-section of the "South Vein" at Rio Tinto.

preferable because it does not necessarily imply mineralisation subsequently to the formation of the rock.

A typical example of this group is presented by certain of the deposits of native copper of Keweenaw Point, Lake Superior. The origin of these deposits is thus ably summarised by M. E. Wadsworth,[1] State Geologist of Michigan: "A deposit of sandstone, overlain by lava-flows, mingled with more or less of inter-bedded conglomerates, and finally overlain by sandstone. Subsequently these beds suffered longitudinal and cross-fracturing and faulting. Later all were acted upon by percolating waters, both hot and

[1] *Report of the State Board of Geological Survey, Michigan, for the Years* 1891 *and* 1892, p. 170.

cold, by which the rocks were altered to a greater or less extent, and the copper was concentrated and stored up in the conglomerates, lavas, and veins, in which it is now found."

It is evident that there are here deposits that show a common origin, but nevertheless belonging to three different groups, namely, disseminations through beds, fissure veins, and disseminations in igneous rocks. It is only with the last named that we are here concerned. The Quincy, Franklin, Huron, Osceola, Atlantic, and in part the Copper Falls mines are all engaged in mining ancient lava-flows, now converted into melaphyrs containing disseminated native copper, which is deposited in all manner of irregular forms, sometimes apparently as a pseudomorph after calcite; with the copper, native silver also occurs, and many specimens are well known in which the copper and silver may be seen in contact in the same lump of metal but not alloyed as would be the case had the lump solidified from the fused state or been exposed to a temperature higher than 1,000°C. subsequently to its formation. Moreover the copper is often found enclosed in, and enclosing zeolites or similar hydrated minerals known to be formed by aqueous agencies, under conditions proving that these minerals and the copper were deposited simultaneously. It is scarcely possible to doubt that the copper was produced by aqueous action, leached according to some authorities out of the overlying heavy lava-flows. Why it was deposited as native copper and not as sulphide, which is the usual form assumed by deep-lying copper ores, it is at present impossible to explain. Pumpelly suggests that copper-salts have been reduced by the action of suboxides of iron which latter were thereby peroxidised, and he thus associates the existence of the native copper with that of the iron ores of the same region.

An interesting example of this group is afforded by certain platinum deposits in Russia. The bedrock of some deposits of alluvial platinum on the rivers Vyzaj and Kaiva, on the western flanks of the Urals, has been found to consist of an olivine gabbro containing disseminated platinum, but not, it would seem, in workable quantities. A similar deposit has been discovered more recently at Goroblago-datsk, on the eastern side of the same mountain chain, consisting of platinum and chromite disseminated in an olivine rock, which has yielded at the rate of 14 dwt. 9 grains of coarse platinum dust to the ton of rock. It is said that this deposit is being exploited.[1]

[1] *Zeitsch. f. Prakt. Geol.* 1893, p. 87.

Numerous other examples might be quoted, but these will suffice to show the general characters of the group; as already pointed out, it has affinities with many other groups, including as it does deposits that may have been formed in many different ways. It is hardly necessary to repeat that this undesirable condition is unavoidable in a transition state of the science, and above all when a classification based partly on genetic and partly on morphological characteristics is employed.

PART II

ORE DEPOSITS OF THE PRINCIPAL MINING REGIONS.

In selecting for description some of the more important ore deposits of the world, they will be grouped in accordance with their geographical distribution, and will be chosen either on account of their economic importance, or because they exhibit unusual and instructive phenomena.

The principal deposits of the various mining countries will be described in the following order:—

EUROPE.—The United Kingdom, France, Belgium, German Empire, Austro-Hungarian Monarchy, Italy, Greece, Spain, Portugal, Scandinavia, Russian Empire with Asia in part, Turkey.

ASIA AND OCEANIA.—Indian Empire, Malay Peninsula, Siam, Malay Archipelago, Philippine Islands, Japan, China, &c., Australasian Colonies, New Caledonia.

AFRICA.—Algeria, Cape of Good Hope, Gold Coast, Transvaal, &c.

NORTH AMERICA.—United States, Dominion of Canada, Newfoundland, Mexico.

SOUTH AMERICA.—Brazil, Chili, Bolivia, Peru, Guiana, Colombia, Argentina, &c.

CENTRAL AMERICA, &c.

EUROPE

THE UNITED KINGDOM

THE most important metalliferous mines of the United Kingdom are situated in the counties of Cornwall and Devon, in Shropshire, Yorkshire, Derbyshire, and North Lancashire, as well as in Cumberland, Westmoreland and Durham. Mining is also extensively carried on in Anglesea and various other parts of Wales, in the Isle of Man, in the south-west of Ireland, and the south and west of Scotland.

ENGLAND

Silver mines were worked in Britain before the invasion of the island by the Romans, and gold must have been well known to the inhabitants of this country before the arrival of Cæsar, since coins of that metal were then in circulation among them. Cæsar and Strabo agree in stating that the Britons obtained their copper from foreign sources, and iron is described by the former as being so rare as to be sometimes employed as a medium of exchange ; a century later, however, it was so common as to have become an article of export. Tin was anciently the most important metallic production of Great Britain, and a desire to obtain possession of the mines producing it, and thereby becoming independent of the Phœnician monopoly, appears to have first induced the Romans to visit the island. About the middle of the sixteenth century mining was less intelligently conducted than on the Continent, as we are told by Sir John Pettus [1] that "About the third year of *Queen Elizabeth*, she, by the advice of her Council, sent over for some *Germans* experienced in *Mines*, and being supplied, she, the tenth of *October*, in the sixth of her reign, grants the *Mines* of eight Counties, besides those in *Wales*, to *Houghstetter*, a *German*, &c., whose name and Family still continue in *Cardiganshire ;* and doubtless we had much of our knowledge from their Predecessors, who revived this work in *Cardiganshire.* They also entered upon another work of *Copper* at *Keswick*, in *Cumberland*."

In addition to having been long pre-eminent as a tin-producing country, England was, for a period somewhat exceeding a century,

[1] *Fodinæ Regales*, 1670, p. 20.

likewise the largest producer of lead, copper, and iron ores. Although still yielding a more considerable amount of iron ore and producing a greater quantity of pig iron than any other country in the world, as far as the other metals are concerned England has at the present time various formidable and successful rivals. Among European countries, Spain may be cited as producing larger quantities of lead and copper, while recent colonial enterprise has resulted in the discovery of large and exceedingly rich deposits of tin ore in Australia and Malaysia.

Cornwall.—The metalliferous rocks of Cornwall comprehend granite and slates, associated in some places either with hornblendic rocks or with *elvans* (quartz-porphyries), which usually form broad dykes intersecting indifferently both granite and slate.[1] Granite occurs in four principal masses, besides several smaller ones, its chief constituents being quartz, felspar and mica ; although, in addition to these, schorl is everywhere more or less abundant. The felspar and mica of Cornish granites are of at least two kinds, and the granitic ground-mass sometimes includes large crystals of both mica and tourmaline. The granite is for the most part somewhat coarse-grained, but varies considerably in this respect in different localities, while the more coarsely crystalline rock is not unfrequently traversed by granite veins of a much finer texture. Spheroidal masses of schorl rock are sometimes enclosed in the granite. Two distinct series of joints intersect the granite nearly at right angles, dividing it into approximate cubes, while others, in intermediate directions, again subdivide it more or less irregularly. The granite of this region frequently exhibits a foliation which roughly approximates to the contour of the surface and imparts to the rock a somewhat gneissoid character.

The slates, which are locally known as *killas*, usually rest on the granite at a considerable angle, but in some cases the junction is nearly vertical, while in others the two rocks are, in the immediate vicinity of their boundaries, considerably mixed. Near the line of junction the granite is not unfrequently extremely fine-grained, while the slate often becomes hard and massive, but differs from the granite in general appearance, as well as in being also much darker in colour. Veins of granite frequently penetrate the slate,

[1] The metalliferous districts of Cornwall have been more carefully described by W. J. Henwood than by any other observer, and I have much pleasure in acknowledging my obligations to his work, "On the Metalliferous Deposits of Cornwall," *Trans. Roy. Geol. Soc of Cornwall*, v., and to his *Address, Royal Institution of Cornwall*, 1871, for much important information.—J. A. P.

and masses of the one rock are sometimes enclosed in the other. In one district, at a considerable distance from any known large body of granite *in situ*, numerous detached spheroidal boulders of that rock have been found enclosed in slate. No general description can be given of the mineralogical composition of the slates of Cornwall, since the nature and proportions of their several constituents are seldom constant over any considerable area. Among their recognisable minerals, however, quartz, felspar, mica, chlorite schorl and hornblende are the most conspicuous. In the vicinity of granite the slates are frequently of a green, brown, purple, or violet hue; but at more considerable distances from it they are often of a gray, bluish-gray, deep-blue, brownish-yellow, or buff colour, and in some localities contain fossils, chiefly of Devonian age. Certain of these slates are distinctly crystalline and possess an imperfect cleavage, while others are highly fissile; all are, however, more or less interlaminated and veined with quartz. The planes of bedding almost invariably dip from the granite, the various layers of slate thus mantling round the slopes of the granitic hills. Sandstones sometimes occur interstratified with the slates, which are also occasionally traversed by dykes of diabase.

Quartz-porphyry usually occurs in the form of dykes known as *elvan courses*, which are sometimes only a few feet in width, but are generally much wider. Less frequently elvan has been met with in apparently isolated masses. Elvan courses traverse granite as well as slate without interruption, and, in one case at least, two lodes would appear to have been intersected by an elvan. Dykes of this rock frequently conform both in direction and dip to one series of joints in the rocks which they traverse, but are rarely conformable with the cleavage planes of the slate. Elvan courses sometimes divide into branches or offshoots, but this occurs less frequently than in the case of lodes. When enclosed in slate, elvans are usually, to a large extent, composed of a compact felspathic ground-mass with quartz and a little schorl or mica, enclosing white, buff, pink, or dove-coloured felspar with crystals of quartz, which are often double-pointed, and of which the faces and edges sometimes appear to be slightly rounded. When passing through granite, quartz and felspar still prevail, and mica and schorl are abundant, as well as are also porphyritically-enclosed crystals of felspar and quartz; but the texture of the ground-mass is usually finer than it is when traversing slates. In both rocks, however, elvan is coarser in grain near the centre of the mass than in the vicinity of its sides.

Numerous joints traverse the elvans in all directions, dividing them into blocks of irregular form; these crevices are in some cases faced with schorl, while in others they are filled either with a white or a ferruginous clay. The quartz of elvans contains fluid-cavities very similar to those found in that mineral when occurring in granite. Throughout the mining districts of Cornwall the run of the elvan courses is a few degrees north of east and south of west, but in other parts of the county they vary considerably from this direction. Their dip is less than that of the lodes by which they are intersected, but greater than the dip of the cleavage planes of the slates which they intersect.

The serpentine of Cornwall is traversed by numerous veins and branches, which sometimes contain native copper, but this metal does not occur in sufficient quantities to entitle the rock to rank among the metalliferous series of the county. Veins of fine-grained granite sometimes penetrate not only the outer edges of the granitic bosses but also the adjoining fossiliferous rocks, including the Culm series. The elvans hold their course straight through the granite and the granitic veins, and these are again traversed by veins containing tin and copper ores. The lodes are, therefore, newer than the elvans, and the most ancient mineral veins of Cornwall are consequently younger than the Carboniferous period; they are, however, probably not more recent than the Permian, since no lodes have been discovered in the sandstones belonging to the Poikilitic group.

In certain exceptional instances it might, at first sight, appear that elvans were posterior to tin veins, but the observations of Sir H. T. De la Beche led him to an opposite conclusion, and he has shown how the cases which have been brought forward in support of that view may be otherwise interpreted.[1] Tin ore occurs disseminated through granites, elvans, and slates, as well as in minute veins in these rocks. Copper ores are sometimes sporadically distributed through the granites, elvans, and slates in the same way that these rocks are impregnated with tin ore. Such impregnations of copper, however, seldom possess any commercial importance.

The principal repositories of the various ores of Cornwall are lodes, which consist to a large extent of quartz, and extend without interruption through every rock of the metalliferous series; they however, in some degree, partake of the characteristics of the different rocks through which they pass. Notwithstanding that

[1] *Report on the Geology of Cornwall and Devon*, 1839, p. 310.

workings often extend for considerable distances on lodes corresponding in direction, it is by no means certain that any individual lode has ever been traced for a length of above a mile. Every lode throws off branches and strings into the adjoining country rock, and this frequently occurs to such an extent that instead of remaining a single *champion lode* the vein becomes divided into a complex and irregular network. A lode will also often dwindle to a mere line, while some of its offshoots become enlarged, and finally exceed, both in size and richness, the vein from which they originally separated. It is by no means unusual for a lode to divide immediately at its point of intersection with a cross-course, on one side of which it will be united, while on the other it is divided into several branches.

Lodes which are approximately parallel in direction dip at various angles or in different ways, and consequently they not unfrequently intersect one another. The results of such intersections are exceedingly various: sometimes such veins unite and continue together for some distance, but at length separate. Not uncommonly one lode is displaced horizontally, or thrown vertically, by the other, while occasionally both are disordered and lose their distinctive characters at the point of intersection. Generally speaking, lodes which yield a mixture of the ores of tin and copper are wider than those which contain ores of only one of these metals. The lodes of Cornwall are wider in slates than in the granite, and their average width is greater within 100 fathoms from the surface than at any greater depth hitherto attained. Henwood furnishes the following figures as the result of his investigations relative to the thickness of Cornish lodes:—

Lodes yielding ores of both tin and copper	average	4·7	feet	in width.
„ „ tin ores	„	3·0	„	„
„ „ copper ores . . .	„	2·9	„	„
„ in granite	„	3·1	„	„
„ in slate	„	3·7	„	„
„ at less than 100 fathoms deep .	„	3·9	„	„
„ at more „ „ „ „ .	„	3·3	„	„

On passing from one rock to another, or from riches to poverty, the width of a lode frequently changes, but under ordinary circumstances a lode commonly maintains, approximately, its characteristic breadth. The directions of lodes in the different mining districts are not perfectly identical, nor are all those occurring in the same neighbourhood strictly parallel.

The central portions of the county are traversed by two systems of veins, namely, *champion lodes* and *counter lodes*, each of which maintains approximately its own normal range; but, even in the most western district, the veins exhibit a certain degree of divergence. Notwithstanding that there is scarcely a point of the compass towards which some lode is not known to tend, and that the lodes in many localities have an approximate coincidence, their mean direction differs materally in various parts of Cornwall.

The mean directions of the lodes in different parts of Cornwall are given by Henwood as follows:—

St. Just	35° S. of E., N. of W.	Redruth	22° N. of E., S. of W.
St. Ives	8° S. of E., N. of W.	St. Agnes	22° N. of E., S. of W.
Marazion	1° N. of E., S. of W.	St. Austell	13° N. of E., S. of W.
Gwinear	2° S. of E., N. of W.	Caradon	18° N. of E., S. of W.
Helston	16° N. of E., S. of W.	Tavistock	9° N. of E., S. of W.
Camborne	20° N. of E., S. of W.		

Their average bearing is about 5° N. of E., S. of W., a course which does not materially differ from that of the granite outcrops which at intervals make their appearance between Dartmoor and the Land's End, and also not unlike the course of a line drawn directly through the centre of the county. Lodes present as many flexures in their downward as in their horizontal direction, and vary in dip from an inclination of less than 45° with the horizon to 90°; the average being probably about 70°. Sometimes, although less frequently, lodes dip in opposite directions in different parts of their range. Both lodes and cross-courses dip more frequently towards the granite than away from it, and veins which maintain a nearly meridional direction are in Cornwall more highly inclined than those coursing more nearly east and west.

Lodes intersecting dissimilar rocks obliquely to their line of junction are sometimes slightly deflected, and for a short distance occasionally pass between them, but they suffer no interruption and soon resume their original direction. In such cases the rocks often occupy corresponding positions on both sides of the vein; sometimes, on the contrary, a faulting of the strata has taken place along the course of the lode, and the horizontal and vertical range of the rocks on its two sides may be very different. Both the composition and structure of lodes is materially influenced by the rocks in their immediate vicinity.

Those parts of the lodes of Cornwall which are most uniform in composition consist chiefly of crystalline quartz containing many fluid cavities, and in such places a distinctly jointed structure of the veinstone is frequently apparent; but where the filling of the vein fissure is made up of more heterogeneous materials, this characteristic is less commonly observed. The quartzose portions of veins are sometimes divided into combs which curve, unite, separate, and again fall together in such a way that, without being strictly parallel, the thicker parts of certain layers adapt themselves to the thinner portions of others.

When lodes coincide in direction with the joints of the enclosing rock, their walls are usually smooth and well defined, but when the joints disappear there is generally a gradual transition from the veinstone to the country rock. Lodes not only afford instances of foliation parallel to their strike, but they are also frequently traversed by cross-joints imparting to them, in some degree, the appearance of horizontal bedding. Fissures in the vicinity of the line of separation between veinstones and the country rock are often filled with flucans which, like slickensides, are frequently scored with curved and unconformable striæ.

Many lodes, from enclosing portions of the adjoining country rock, present a brecciated appearance. Lodes of this character are not uncommon in both granites and elvans, but are most conspicuous in slates. In some instances these inclusions have the form of roughly lenticular or sheet-like bodies; occasionally they are sharply defined, while sometimes they appear to pass by imperceptible gradations into the surrounding veinstone. Less frequently they are enclosed in successive accretions of quartz, each distinguishable by some peculiarity of either structure or colour. Small cavities surrounded by botryoidal concretions of agate-like silica, often lined with crystals of quartz, occur at intervals between the fragments of included rock. When these fragments consist of slate, their planes of cleavage are almost always coincident with those of the enclosing country rock, but when the country consists of either granite or elvan, the pieces included in the lode being of the same material, their general resemblance to the veinstone is so close that their relations are less easily detected. When such phenomena occur on the line of contact of different rocks, their planes of junction observed in the enclosed horses are on precisely the same horizon as their counterparts in the rock by which the lode is enclosed. Felspar is abundant in all lodes passing through granites and elvans, but in slate, quartz is the predominating veinstone. The outcrops and shallower portions of nearly all lodes are usually to some extent composed of gossan, consisting of an earthy iron ore mixed with granular quartz, and frequently containing oxide of tin with other metalliferous minerals.

When tin lodes traverse the granite, their most productive veinstone is usually pale green or brownish-red felspar, imperfectly crystalline, and associated with quartz and schorl; but quartz and schorl are sometimes abundant ingredients, and occasionally quartz prevails. The tin oxide is usually present in the form of crystalline granules which seldom exceed the size of a pea, but are more often microscopically minute. In slate, tin lodes consist chiefly of capel or quartzose slate, chlorite, quartz and schorl, in thin alternations. The ore is disseminated in even more minute particles among these minerals than it is in the lodes of which the country rock is granite. Copper lodes in granite have almost always an outcrop of gossan, which sometimes extends to considerable depths; but the quartz associated with them is rarely so friable as it is in similar deposits enclosed in slate. The cavities which occur in this slightly coherent material, often contain earthy brown iron ore, coloured clays, black copper ore and malachite. At greater depths fluor spar is not an uncommon veinstone, while black copper ore is frequently succeeded by chalcocite, and this by copper pyrites. In one of the most important mining localities of Cornwall, the outcrops of many of the lodes were anciently worked for the tin ore which they afforded near the surface. On proceeding downwards, however, the tin became gradually replaced by copper ores, of which the lodes were for some time most productive repositories; still deeper, tin ore reappeared, and for many years this has been almost the only metalliferous product of the neighbourhood. Many lodes contain arsenical pyrites, which is very persistent and appears even to become more abundant in depth. Copper lodes in slate often contain large quantities of spongy, pale-brown or yellowish iron ore, with a small proportion of oxide of tin, and iron pyrites in considerable abundance, with more or less blende and galena. Their other constituents are quartz, which in the more productive lodes is often exceedingly friable, and is mixed with *prian* or felspathic clay; less frequently with chlorite or *peach*, and still more rarely with fluor spar. Near the surface these minerals are often associated with iron pyrites, earthy black copper ore, and malachite, and these are succeeded by chalcocite, which, together with all the other metalliferous minerals, is ultimately replaced by chalcopyrite. Notwithstanding that the ores of tin and copper often affect different lodes, and even different rocks, they are, nevertheless, intimately associated in some of the most productive veins of the county. Ores of lead for the most part occur at some distance from the granite, and are principally limited to groups of lodes traversing slaty rocks in a different direction from those producing tin and copper.

It has been before stated that the most compact portions of the lodes of Cornwall are chiefly siliceous, and that they are sometimes composed entirely of quartz; occasionally, however, the whole substance of a lode becomes metalliferous. The alteration from poverty to riches is seldom a sudden one, since the veinstone in the neighbourhood of large bodies of ore usually becomes increasingly impregnated with the same mineral as it approaches the larger mass. In all lodes, whatever may be the nature of the ore which they produce, the most highly inclined portions are the most productive; and almost all bodies of ore, whether of tin, copper, or lead, have an end-long dip, usually approximating to the foliation of the enclosing granite, or to the bedding or cleavage-planes of the surrounding slates. Lodes and branches are frequently richer at their junction with one another than they are elsewhere; particularly when they come together horizontally or on their dip so as to form an acute angle. When lodes of a soft or granular character pass into a rock of more than ordinary hardness, they frequently divide into numerous branches; while the same effect is sometimes produced by the passage of a lode into unusually soft strata.

Rocks possessing a considerable degree of hardness are more frequently productive of tin than they are of copper, and, both in granite and in elvan, a well-defined porphyritic structure is regarded by miners as an unfavourable indication; while in both rocks a gradual blending of the included crystals with the surrounding ground-mass is considered an encouraging circumstance. Transverse joints often exercise an unfavourable influence on the production of a lode, and a course of ore sometimes terminates abruptly at such a fissure. During many years the chief produce of two important and almost adjoining tin mines in Cornwall was obtained from deposits of which examples on a large scale are not met with in other parts of the county. These deposits, which are locally known as "carbonas," will be again referred to in connection with the tin deposits of the St. Ives district.

Veins which chiefly consist of quartz, and which with rare exceptions yield neither ores of tin nor copper, are in the St. Just district called *guides*, while in the neighbourhood of St. Ives they are known as *trawns*, and in other parts of Cornwall as *cross-courses.* When such veins consist of clay only, they are called *flucans.* In the following table Henwood applies the term *cross-vein* to both varieties. The mean directions of cross-veins in different parts of Cornwall are as follows :—

St. Just	26° N. of E., S. of W.	Redruth	35° S. of E., N. of W.
St. Ives	38° S. of E., N. of W.	St. Agnes	39° E. of S., W. of N.
Marazion	41° S. of E., N. of W.	St. Austell	21° S. of E., N. of W.
Gwinear	43° E. of S., W. of N.	Menheniot	3° N. of E., S. of W.
Helston	21° S. of E., N. of W.	Caradon	13° E. of S., W. of N.
Camborne	34° E. of S., W. of N.	Callington	43° S. of E., N. of W.

Their average bearing throughout the county is about south-east to north-west, which does not differ materially from that of one of the most distinctly developed series of joints in the rocks. The average inclination of cross-veins maintaining the general range is about 80°, whereas that of those which run more nearly east and west scarcely exceeds 60°. Their dip is more frequently towards the granite than in the contrary direction.

Cross-veins are wider in granite than in slate, and at great depths than near the surface.

The mean width of cross-veins in granite averages		4·9	feet.
,, ,, ,, ,, slate	,,	3·5	,,
,, ,, at less than 100 fathoms deep		4·0	,,
,, ,, at more ,, ,,	,,	4·4	,,

Cross-veins, like lodes, partake of the nature of the different rocks through which they pass; thus in granite, notwithstanding the occasional occurrence of quartz, the principal constituents are the minerals of which granite is composed. In homogeneous slate, on the contrary, they are not unfrequently flucans consisting of triturated slate. Sometimes cross-veins are only developed at certain depths from the surface, and disappear both horizontally and vertically within very short distances.

Small quantities of copper and silver as well as of the ores of these and other metals occur in cross-veins, but they are frequently, although not always, limited to those portions of the vein which pass through lodes in which such metals and ores prevail. A large proportion of the richest lead veins in the county of Cornwall have, however, nearly the same direction and mineral characteristics as the principal cross-veins. Cross-veins, intersecting both the rocks and lodes through which they pass, when composed of cavernous quartz, afford almost the only natural channels for the ready circulation of underground waters; on the other hand those portions which have been filled with flucan are so thoroughly impermeable that they are, for this reason, not unfrequently chosen as the boundaries of areas leased for mining purposes. Slides have been observed in the schistose rocks of certain mining districts only.

It is of great importance that the miner should be in a position to judge whether the chances of successful search for a severed vein are greatest towards the right or towards the left hand, and the following information relative to this subject will not be without interest.[1] Out of 272 lodes recorded by Henwood as being divided by cross-veins in different parts of Cornwall,—

57 or 0·20 of the whole number were intersected but not heaved.
135 „ 0·50 „ „ were heaved towards the right hand.
80 „ 0·30 „ „ „ „ left hand.
181 „ 0·67 „ „ „ „ greater angle.
34 „ 0·13 „ „ „ „ smaller angle.

The following are the results of the intersection of lodes, affording ores of different metals, by cross-veins :—

Nature of ore contained in the lodes.	Lodes intersected but not heaved.	Lodes heaved towards the			
		Right hand.	Left hand.	Greater angle.	Smaller angle.
Tin ore	0·18	0·56	0·26	0·52	0·30
Tin and copper ores .	0·37	0·44	0·19	0·56	0·07
Copper ore	0·18	0·52	0·30	0·74	0·08

The mean distance to which lodes of more than two feet in width are heaved by cross-veins more than one foot wide is . . . . 28·3 feet.

The mean distance to which lodes of less than two feet in width are heaved by cross-veins more than one foot wide is . . . . 16·1 feet.

[1] The direction of a heave is generally indicated by *right* and *left*, because the same expression serves equally well whichever side the dislocation is approached from.

The mean distance to which lodes of more than two feet in width are heaved by cross-veins less than one foot wide is	17·0 feet.
The mean distance to which lodes of less than two feet in width are heaved by cross-veins less than one foot wide is	4·8 feet.

Henwood states that there is at least one instance on record of a lode and a cross-vein alternately intersecting one another at different depths in the same mine.

Elvans traverse the same districts as the lodes, and owing to various differences of direction and dip are frequently intersected by them. The cross-veins cut through elvans and lodes alike, but while they heave hundreds of the latter, they displace scarcely a dozen of the elvans intermixed with them and through which they also pass.

Thermal springs of saline waters have at different times been met with in some of the deeper workings in the neighbourhood of Camborne. Among the mines in which such springs have been observed are those of North Roskear, North Crofty, Huel Clifford, and Huel Seton. The waters issuing from the first two of these localities do not appear to have been subjected to chemical analysis, but that from Huel Clifford was analysed in 1868 by Dr. W. A. Miller.[1]

This water issued at a temperature of 125° F., and at the rate of 150 gallons per minute, in the 230-fathom level, or at a depth of 1,320 feet below the sea. Its specific gravity was 1·007, and the saline constituents were found by evaporation to amount to 646·1 grains per imperial gallon, consisting of:—

Chloride of lithium	26·05
Chloride of potassium with a little chloride of cæsium	14·84
Chloride of sodium	363·61
Chloride of magnesium	8·86
Chloride of calcium	216·17
Sulphate of calcium	12·27
Silica	3·65
Oxides of iron, aluminium, and manganese	traces
	645·45

[1] *Report of the Thirty-fourth Meeting of the British Association*, 1864, p. 35.

The workings at Huel Seton have been entirely confined to the killas or clay slate. In 1872 saline waters issued at the rate of 50 gallons per minute, and at a temperature of 92° F., from the eastern fore-breast of the 160-fathom level, or at a depth of about 780 feet below the sea. At this place the lode is not well defined, and had been driven upon until a cross-vein was intersected, from which the water issued. A short distance from this point, an elvan course, forty feet in width, is traversed by the same vein. An analysis of this water afforded me results which may be tabulated as follows; although, as the state of combination of the various substances present cannot be positively determined, the system of grouping adopted may be regarded as to some extent arbitrary.[1]

The solid matter amounted to 1005·61 grains per gallon, or 14·3658 grammes per litre.

	Grains per gallon.	Grammes per litre.
Calcium carbonate	6·45	·0921
Iron ,,	·31	·0045
Manganese ,,	trace	trace
Calcium sulphate	2·12	·0303
Cupric chloride	trace	trace
Calcium ,,	473·88	6·7697
Magnesium ,,	11·98	·1712
Aluminium ,,	63·02	·9003
Potassium ,,	6·43	·0919
Cæsium ,,	trace	trace
Sodium ,,	409·09	5·8442
Lithium ,,	34·22	·4888
Potassium bromide	trace	trace
Potassium silicate (K_2SiO_3)	4·85	·0693
Ammonia	trace	trace
Nitric acid	trace	trace
Total found by addition	1012·35	14·4623
Total found directly[2]	1005·61	14·3658
Free carbonic acid	2·61	·0373

These waters are remarkable for the large amount of lithium which they contain, but both Huel Clifford and Huel Seton Mines are now abandoned, and the springs consequently submerged.

[1] J. Arthur Phillips, "On the Composition and Origin of the Waters of a Salt Spring in Huel Seton Mine," *Philosophical Magazine*, Fourth Series, xlvi., 1873, p. 26.

[2] The difference between the amount of total solid contents, as found directly, and that obtained by the addition of constituents, is doubtless to some extent due to the partial decomposition of aluminium and magnesium chlorides during the drying of the residue.

Minute quantities of the heavy metals, other than copper, were not sought after.

The mining districts of Cornwall are separable into two great divisions, that of the West and that of the East; the former lying to the west of Truro, and the latter to the east of that city. From the Land's End, a metalliferous country extends almost without interruption to the parish of Kea near Truro; here a break occurs until we approach the neighbourhood of St. Austell, where another metalliferous area commences and extends in an irregular and scattered manner into Devonshire. These divisions are of very unequal extent, the western being about thirty-six miles in length with a width from sea to sea varying from six to fourteen miles, while the eastern extends for a length of nearly forty-five miles with an average width of about twenty miles. The area of the eastern region thus exceeds that of the western in the proportion of two and a half to one; its annual production of the metals is, nevertheless, so greatly inferior that, in value, they have in the aggregate amounted to less than one-fifth of that of the ores raised in the other division.

The mining regions of this county have been divided by Henwood into twelve distinct districts, while Mr. H. C. Salmon[1] subsequently extended this number to twenty; for the purposes of the present work it will, however, be found more convenient to adopt the classification of Mr. Robert Hunt, Keeper of Mining Records,[2] who in his returns grouped the whole of these districts into four large divisions:—

Western Division.	All those parts of the county west of a line drawn from Marazion to Hayle.
West Central Division.	That portion of Cornwall west of a line drawn from the Dodman Point to Padstow, and east of Marazion and Hayle.
East Central Division.	That part of the county lying west of a straight line drawn from Looe through Liskeard to the boundary of the county, and east of the Dodman and Padstow line.

[1] *Mining and Smelting Mag.*, v., 1864, p. 260.

[2] With the retirement of Mr. Hunt in 1882 from the Mining Record Office, and the transference of that office to the Home Office, this splitting up of the county into four divisions has been discontinued, and statistics are issued of the county as a whole. Artificial boundaries in geological study are always to be avoided if possible, and there seems to be no advantage in maintaining the old system here, so that more recent statistics will be given for the county as a whole and not by divisions.—H. L.

Eastern Division. — This division is bounded on the west by a line drawn from Looe through Liskeard to the boundary of the county, and extends eastward to the River Tamar.

Western Division.—The more important mines of this division of the county are situated in the vicinity of the towns of St. Just and St. Ives. In the neighbourhood of the former the principal mines are comprised within an area six miles in length and three in breadth, about a mile south of Cape Cornwall, forming at this point the extreme western limit of the county, and bounded by the Atlantic Ocean. They are, for the most part, situated in the parish of St. Just, and have long been celebrated from being perched on the sides of perpendicular cliffs, and from being excavated for long distances under the bed of the sea. The country inland is composed entirely of granite ; but nearly parallel with the coast and coinciding with the metalliferous ground, this rock forms a junction with clay slate, largely and confusedly intermixed with foliated hornblendic rocks. The older workings, which are of very remote date, were entirely confined to the granite, which is exclusively productive of tin ; but more recently the slates and their associated hornblendic rocks have also produced large quantities of copper ores. Some lodes are exclusively productive of tin ore in the granite and of copper ores in the slates ; Henwood states that at Botallack, one of the lodes was found to pass three times from granite to slate, and in each case to contain tin ore only in the former, and copper ores only in the latter rock. In this neighbourhood, the intersections of the different veins by one another are sometimes attended with complicated and somewhat obscure phenomena. In a few cases the heaves are regular, but they are generally far from being so, and not unfrequently a lode which has continued rich up to its contact with a cross-vein has never been discovered on the other side. As is the case in other localities, the lodes of St. Just are not productive throughout their whole extent, and when poor they are usually small ; poverty appearing to be often accompanied by a diminution of size. The containing rock, which is everywhere in this neighbourhood very hard, often becomes still harder when impoverishment takes place. In all the veins of this part of Cornwall the shoots of ore dip from the granite, or if they occur in that rock their direction is towards the slate. The direction of the lodes, and this general disposition of the ores, have had the effect of directing many of the workings towards the sea, and several of the mines are wrought to some extent beneath the bed of the Atlantic. At Little Bounds, Botallack, and Huel Cock the miners have been tempted to follow the ore upwards to the sea, but the openings made being fortunately small and the rock hard, a covering of wood and cement in the two former cases, and a plug of wood in the latter, were sufficient to exclude the water and to secure the workings from inundation. The extent to which the excavations of some of the mines in the St. Just district have been prosecuted under the ocean, will be understood when it is stated that the diagonal shaft on the Crowns Lode at Botallack has a total length of 345 fathoms for the most part beneath the sea, passes through a very hard hornblendic rock at an inclination of 32½° from the horizon, and occupied four years in sinking.

Botallack was worked as a tin mine, under a perpetual grant from the Boscawen family, from 1721 to 1735, when the sett was relinquished. Subsequently to this the mine was again opened, and in 1816 was the richest in the county. It was afterwards worked as a copper mine, but in 1844 was again about to be abandoned; a rich copper lode was, however, discovered at this time, and in the following year the undertaking had again become prosperous.

The production of tin and copper ores at Botallack during forty years, divided into decades, together with the value of the yield of each several ten years, is given below.

	Tin Ore.		Copper Ores.	
	Tons.	£	Tons.	£
Ten years to the end of 1861	1,495	112,331	7,438	85,984
,, ,, 1871	4,020	265,652	3,116	24,481
,, ,, 1881	3,868	190,704	1,869	16,752
,, ,, 1891	2,957	163,116	207	1,879

The annual production since 1891 has been:—

	Tin Ore.		Copper Ores.	
	Tons.	£	Tons.	£
1892	350	18,468	Nil.	
1893	402	19,164	Nil.	
1894	390	15,424	12	136

Its production of recent years has thus been practically confined to tin.

In these mines, as well as at Huel Edward and at Levant, the dashing of the waves against the cliffs, and the grating of the shingle on the bottom, can be heard even in moderate weather. The quantity of underground water throughout the neighbourhood is extremely small, and notwithstanding that it is somewhat salt in the workings extending beneath the sea, the amount is not perceptibly greater than in mines situated at some distance inland.

The only producing mine of the St. Just group now left is Levant, which produced in 1894:

	Tons.	£
Copper ore	1,882	7,577
White arsenic	192	1,243
Tin ore	629	26,109

The above copper production represents three-fourths of the value of the annual copper output of the whole county.

The St. Ives mines, on the opposite side of the Land's-End mass of granite, occupy a position somewhat analogous to those of St. Just. The granite forms a similar junction with the clay slate or killas of St. Ives Bay, which is in the same way much intermixed with various hornblendic rocks. The lodes, which occur in both granite and slate, are in the former exclusively productive of tin; while in the latter, as well as in the hornblendic rocks, copper ores often predominate. Little or no copper is, however, at present, raised in this neighbourhood, and its production of tin is much less important than formerly, since many of the most extensive mines, having ceased to yield remunerative returns, are no longer in active operation. The extreme length of this mining field in a north-westerly direction skirting the granite, is about four miles, and its greatest width nearly three miles. It includes the larger proportion of the three parishes of St. Ives, Lelant, and Towednack, and possesses some marked peculiarities, one of the most notable being the presence of carbonas or extensive disseminations of tin ore extending from some of the lodes into the neighbouring granite. Large and rich masses of tin ore have also, from time to time, been met with surrounded on all sides by hard granite, and apparently unconnected with any lode or vein.

The direction of the lodes is rather to the N. of E. and S. of W., while that of the cross-courses is within a few degrees of N. and S., having approximately the strike of the joints of the adjoining rock. The veins worked in granite usually produce tin ore, while those in slate, although sometimes also yielding tin, more frequently afford copper ores. Tin has, however, always been the staple product of the mines in this neighbourhood.

The most remarkable mine in the western division of Cornwall is, perhaps, St. Ives Consols, which is situated in granite, although at only a short distance from the junction of that rock with hornblendic schists and quartz-diabase, which appear immediately to the east, where they overlie the granite as seen in some of the eastern shafts. It lies immediately west of the town, and the principal lode traverses the bottom of the valley through which flows the stream falling into the sea at St. Ives. The vein which passes through the valley above referred to is known as the Standard Lode, and is nearly vertical, its bearing being a little N. of E. and S. of W. The accompanying transverse section of

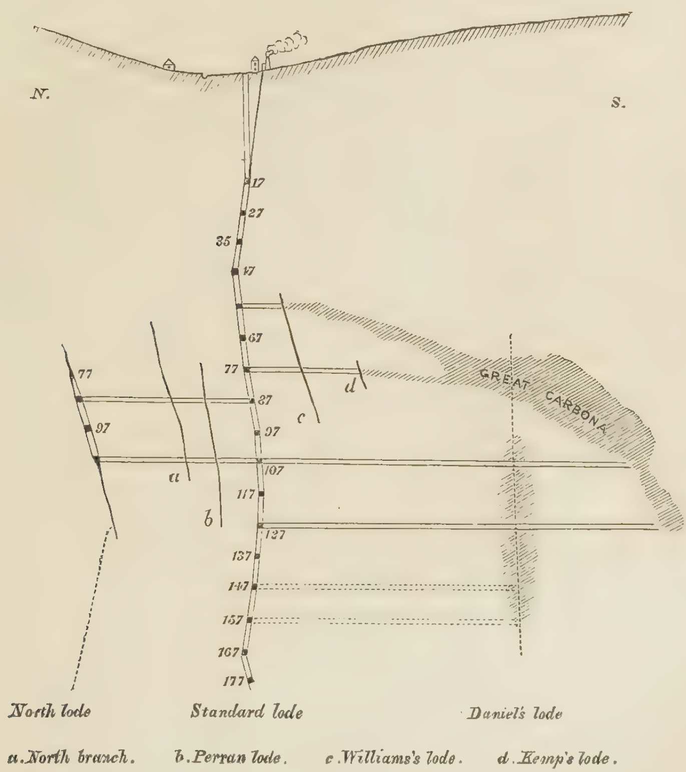


FIG. 68.—Standard Lode and Carbonas, St. Ives Consols; after H. C. Salmon.[1]

this lode, Fig. 68, shows how slightly its course downwards varies from the perpendicular, as well as its connection with the various carbonas.

The Standard Lode has been worked to a depth of 177 fathoms below the adit level, which is itself twenty fathoms from the surface, thus making the total depth of the mine nearly 200 fathoms.

[1] *Mining and Smelting Magazine*, iii. p. 140.

In the lower levels this lode is hard and unproductive, so that but little has been done at that depth, and the workings in the bottom have been many years abandoned. The Standard has, in the aggregate, been a very productive lode, although it is nowhere large, and probably does not average more than four and a half feet in width, varying however considerably in this respect. It is chiefly composed of quartz, chlorite, decomposed granitic matter, and schorl; the latter being plentiful where tin is abundant.

The most striking feature of this mine is, however, the extraordinary deposits of tin ore which have been found south of the Standard Lode and to which the name of "carbonas" has been locally given (see page 170). Fig. 68 affords some idea of the way in which these carbonas branch off from the Standard Lode. One of them, called Lawry's Carbona, shoots off at the 57-fathom level, dipping rapidly as it goes south, and forming stanniferous flats of various dimensions which have been worked by a series of irregular caverns, very unlike the openings resulting from ordinary mining operations. Another, uniting with the Great Carbona, goes off at the 77-fathom level; and at about forty fathoms south of the Standard, the level driven on the western cross-course intersects what is called Kemp's Lode, bearing nearly north and south, which is itself apparently part of a carbona. This so-called lode was driven upon for some distance until it came in contact with Noal's Lode, and with flats and droppers coming down from Lawry's Carbona, at its junction with which the whole opened out into one of the most remarkable deposits of tin ore ever discovered in Cornwall.

Many of the workings are in the form of enormous caverns from 60 to 75 feet in height and equally wide. The workings on the Great Carbona were destroyed many years ago by an accidental fire which consumed the supporting timbers, and, after burning for more than six weeks, at the end of that time left the whole in a state of utter ruin. All the carbonas occur south of the Standard Lode, and wherever they are productive they are characterised by the presence of large quantities of schorl.

The workings on Daniel's Lode are remarkable for their immense width, which often reaches upwards of 40 feet, although when unproductive it is barely traceable. This deposit, although generally called a lode, evidently belongs to a class of disseminations much resembling carbonas. St. Ives Consols was worked above the adit level only in recent years, and a large portion of its produce was obtained from the treatment of "halvans"[1]; in 1881 it yielded 52 tons 12 cwts. 2 qrs. 23 lbs. of concentrated tin ore (black tin) of the value of £2,755, and its output continued to fall off rapidly even from this low figure; it was only 24 tons in 1887, 10 tons in 1888, only 4 tons in 1891, and may now (1894) be considered as practically worked out.

The total production of the mines of the western division of Cornwall during the year 1881 was, according to the statistics published by the Mining Record Office, as follows:—

	Weight.			Value.		
	Tons.	cwts.	qrs.	£	s.	d.
Black Tin	1,362	8	2	73,395	19	8
Copper Ore	1,190	1	0	8,127	13	9
Totals	2,552	9	2	81,523	13	5

West Central Division.—This extends over a much larger area than the western division, and comprehends a great proportion of the most important mines in the county.

Those near Marazion are situated in a basin of killas stretching from that town eastward along the coast of Mount's Bay for a distance of upwards of four miles to the mass of granite culminating at Tregoning Hill. Its width from the sea inland is about three miles, comprising the parishes of St. Hilary and Perranzabuloe, with parts of Breage and Germoe. The mines distributed over this district have, in the aggregate, yielded large quantities of copper and tin, but principally the former, which appears to generally occur in the vicinity of elvan courses; the district has not, however, been characterised by any very deep or permanent mines.

The mines of the Breage and Sithney district occupy a killas basin lying between the granite of the Tregoning and Godolphin Hills and the larger granitic mass of the Wendron range. It is very restricted in length, since it skirts the smaller mass of granite from north to south without extending any considerable distance eastward. It includes the larger portions of the parishes of Breage and Germoe with a part of Sithney, and is almost exclusively a tin-producing area, having yielded some of the richest and deepest deposits of tin ore which have been found in Cornwall. Although this district consists principally of killas, its granite has also yielded tin.

[1] Refuse ore thrown aside as not being, at the time, sufficiently rich to pay the expenses of treatment.

In the parishes of Gwinear, Crowan, Phillack, and St. Erth are various copper mines which are usually productive in the neighbourhood of elvan courses. The country rock is generally slate, varying in colour from blue to pale buff, but sometimes made up of alternate blue and white laminæ. At Relistian the slate contains numerous spheroidal concretions, some of which are apparently composed of slaty material, while others are entirely quartzose. In the neighbouring mine of Herland, at a depth of about 110 fathoms, numerous nodular masses of granite have been found enclosed in the killas. These, which vary from half an inch to three feet in diameter, are composed of a fine-grained granite, the felspar of which is much decomposed. They are entirely surrounded by clay slate, and have no apparent connection with one another. Elvan courses and dykes of "greenstone" are numerous in this neighbourhood, and the elvan often contains a large quantity of schorl. It is sometimes stanniferous, and has in a few localities been worked for the tin it contains. At Parbola the elvan is everywhere traversed by minute strings of tin ore. A striking characteristic of the lodes in this part of Cornwall, which is very unusual in other parts of the county, is that they, as well as the contiguous rocks, contain large quantities of the globular concretions already noticed. Copper pyrites and copper glance are the most abundant minerals, but tin ore is, to some extent, found in a large number of the mines.

The mining districts of Wendron, Camborne, Redruth, and Gwennap are in connection with the great granite range of Carn Menelez and the two smaller associated masses of Carn Brea and Carn Marth. The Wendron mines are situated in the granite of the Carn Menelez range, and are principally in the parish of Wendron, although they also extend into the parishes of Sithney, Crowan, and Constantine. This is a wild moorland district, and although producing considerable quantities of tin ore, it does not possess any very characteristic mining features.

Some of the mines of the Camborne district are at the present time the richest in Cornwall, and are comprised within those portions of the parishes of Camborne and Illogan bounded on the east by the valley which divides Illogan from Redruth; on the south by a line passing through the ridges of Carn Brea, Carnarthen Carn, and Camborne Beacon; on the west by a line drawn from Camborne Beacon to about half a mile north of Camborne Church; and on the north by the highway from Camborne to Redruth. The prevailing rock is granite, which rises on the south into an elevated range of hills, whose northern slope is covered by killas traversed by various elvans, lodes, and cross-courses. The mines of this neighbourhood are the deepest in Cornwall, and are remarkable for being at great depths as rich for tin as they were formerly for copper in the shallower levels.

The table on following page, giving the annual production of copper and tin ores at Dolcoath Mine from 1850 to 1894 inclusive, indicates the very gradual way in which this undertaking has become transformed from a copper mine to one producing tin ores only. The shallower levels of this mine were driven exclusively in killas, while the deeper workings are entirely in granite. In killas the lodes produced large quantities of copper ore, but upon entering the granite this ore became rapidly replaced by cassiterite. At the present time Dolcoath is the deepest mine in Cornwall, the engine shaft having reached a depth of 400 fathoms.

The difficulties of working at increasing depths with the old underlie shaft and the expense connected with it became at length too great, and in 1895 a reform was inaugurated here, not indeed before it was needed, that may be expected to have a salutary effect upon Cornish mining generally. The old cost-book method was given up, and the mine was transferred to a Limited Liability Company with ample capital; a new vertical shaft has been commenced, through which, when down, all winding will be carried on economically upon modern scientific principles.

PRODUCTION OF DOLCOATH MINE FROM 1852 TO 1891.

		Copper Ore.		Tin Ore.	
		Tons.	£	Tons.	£
Nine years ending	1861	6,410	26,926	5,063	368,918
Ten ,,	1871	3,776	18,826	9,654	637,962
,, ,,	1881	223	1,019	14,214	764,383
,, ,,	1891	3	10	22,098	1,236,256

During forty years, namely, from 1851 to 1891, East Pool Mine, near Camborne, produced ores of the following weights and values :—

	Copper Ore.		Tin Ore.	
	Tons.	£	Tons.	£
Ten years to end of 1861	20,208	100,417	416	25,895
,, ,, 1871	22,444	72,333	2,174	129,961
,, ,, 1881	18,603	55,054	6,161	283,806
,, ,, 1891	3,055	9,028	13,111	687,541

In 1894 the production was :—

	Tons.	Value.
Copper ore	730	£1,092
Tin ore	940	£33,930

P 2

In this mine too the falling off in copper ores and the increase in tin ores with depth is very noticeable.

Amongst other important mines of this district may be mentioned Carn Brea, which produced in 1894 tin ore to the amount of 1,243 tons valued at £40,118; this mine has been noted as a steady producer for many years.

PRODUCTION OF DOLCOATH MINE FROM 1850 TO 1894 INCLUSIVE.

Year.	Copper Ore.			Tin Ore.	
	Tons.	Value.	Produce.	Tons.	Value.
		£			£
1850	1,115	4,909	$6\frac{1}{2}$	—	—
1851	801	3,266	$6\frac{7}{8}$	—	—
1852	832	3,344	$5\frac{1}{8}$	—	—
1853	1,040	4,920	5	360	22,680
1854	992	4,313	$4\frac{1}{2}$	363	25,261
1855	711	2,634	4	352	23,169
1856	617	1,998	$3\frac{7}{8}$	416	30,727
1857	566	2,430	$4\frac{1}{2}$	544	42,880
1858	598	3,085	$6\frac{1}{16}$	635	41,859
1859	757	3,531	$5\frac{1}{8}$	724	53,506
1860	712	2,426	4	805	64,974
1861	417	1,589	$4\frac{1}{2}$	864	63,862
1862	508	2,357	$5\frac{7}{8}$	986	66,220
1863	636	3,029	$6\frac{1}{4}$	1,026	69,741
1864	621	3,289	$6\frac{1}{4}$	1,030	66,959
1865	607	3,510	$7\frac{3}{8}$	944	53,238
1866	688	3,512	$7\frac{1}{2}$	919	46,120
1867	267	1,068	$5\frac{1}{8}$	848	46,169
1868	153	863	$8\frac{1}{8}$	984	55,847
1869	153	648	$6\frac{7}{8}$	813	59,694
1870	57	224	—	1,034	78,601
1871	86	326	$6\frac{1}{2}$	1,070	95,373
1872	50	234	—	1,269	113,114
1873	15	72	—	1,045	82,501
1874	73	410	—	1,121	65,558
1875	—	—	—	1,241	65,346
1876	41	163	—	1,263	55,825
1877	30	112	—	1,404	59,180
1878	14	28	—	1,539	55,902
1879	—	—	—	1,780	71,216
1880	—	—	—	1,736	93,702
1881	—	—	—	1,816	102,039
1882	—	—	—	1,976	120,244
1883	—	—	—	1,876	101,707
1884	—	—	—	2,423	113,965
1885	—	—	—	2,555	124,998
1886	—	—	—	2,383	134,881
1887	—	—	—	2,366	152,241
1888	—	—	—	2,239	148,734
1889	3	10	—	2,125	114,029
1890	—	—	—	2,024	110,696
1891	—	—	—	2,132	114,761
1892	—	—	—	2,536	139,818
1893	—	—	—	2,421	124,841
1894	—	—	—	2,126	89,347

Among the most remarkable phenomena exhibited in this part of Cornwall are the alternations and mixtures of granite and slate which occur near the line of junction of the two rocks in the mines of Cook's Kitchen, Tincroft, Dolcoath, and Carn Brea. In the southern part of Cook's Kitchen a friable, coarse-grained granite appears at the surface and continues downwards to a depth of about thirteen fathoms, where it is succeeded by a bed of slate which reaches a depth of thirty-nine fathoms. The upper portion of this mass of slate is of a deep blue colour, and has a distinctly crystalline structure, showing, somewhat obscurely, evidences of foliation. Lower down it becomes gradually more micaceous, and shows well-defined planes of cleavage. Veins of granite penetrate both the upper and lower surfaces of the slate. Below this there is a bed of fine-grained granite, ten fathoms in thickness, containing a large amount of schorl, beneath which masses of granite and of slate alternate in a very irregular way. The transitions from one to the other are sometimes gradual, while at others they are very abrupt, and in nearly all cases the slates are traversed by veins of granite.

At Tincroft the granite goes down to a depth of twenty-six fathoms from the surface, at which point the slate makes its appearance, and continues without interruption to a depth of eighty-four fathoms, where at length the main body of the granite appears.

At Dolcoath a large mass of hard slaty rock was met with in 1882 in the 352-fathom level, east of the new eastern shaft, at a total depth of 380 fathoms from the surface. This slate is included in the granite 240 fathoms below the point where that rock was first cut into by the workings, and 310 fathoms below the sea level. This enclosure closely resembles the ordinary killas of the district, and on comparing thin sections of the two, as seen under the microscope, their identity becomes at once apparent.

The Redruth and Gwennap district immediately adjoins, on the east, that of Camborne, so that an arbitrary line only can be drawn between them. The district includes the parishes of Redruth and Gwennap, with parts of Kenwyn, Kea, and St. Agnes. It is essentially a copper-bearing neighbourhood, and formerly produced very large quantities of that metal, but for many years its productiveness has gradually fallen off, and many of its once rich copper mines may now be regarded as exhausted. The Great Consolidated Mines of Gwennap in the course of twenty-one years (1819—1840) sold ores to the value of £2,254,485, of which £480,156 was divided as profit. Some important mines were formerly worked along the north coast of the county in the parish of St. Agnes, and in the western portion of Perranzabuloe. They have been largely productive of tin and copper, the ores of both metals appearing to be most frequently met with in the vicinity of elvans.

The Great County Adit of Cornwall empties itself into the Carnon stream, which falls into Restronguet Creek, and extends to many of the mines in the vicinity of Redruth. Its greatest depth from the surface is seventy fathoms, its total length, including branches, thirty miles, and the level of its mouth above high water thirty-nine feet. It is at present of comparatively little importance, as many of the principal mines in connection with it are worked out and abandoned. Many years ago it drained an area of 5,550 acres, and discharged on an average 1,450 cubic feet of water per minute. A little copper is sometimes obtained from the waters of this adit by precipitation by scrap-iron.

Numerous lead veins, running in almost every direction, occur in a district lying north of Truro and comprising a large portion of the parishes of Perranzabuloe, Newlyn, Cubert and Crantock. This region has produced one or two rich lead mines, and several moderately productive ones. For a long time East Huel Rose was the most productive lead mine of this district, but eventually it was submerged by an accidental influx of surface water during a flood. It subsequently remained unworked for many years, but has more recently been again set in operation. Its production from 1844 to the end of 1861 was as follows:—

Year.	Lead Ore.	Lead.	Silver.
	Tons.	Tons.	Oz.
1845	7,883	4,729	—
1846	5,191	3,114	—
1847	6,424	3,854	—
1848	5,333	3,191	—
1849	4,759	2,856	—
1850	4,206	2,524	—
1851	3,193	2,234	—
1852	2,381	1,607	48,000
1853	1,357	925	27,499
1854	1,215	828	24,629
1855	2,343	1,510	46,760
1856	2,691	1,776	53,280
1857	1,199	791	23,739
1858	726	416	10,400
1859	728	386	13,090
1860	607	322	10,948
1861	147	66	2,376

This mine sold copper ore in the following years:—

	Tons.		£
1850	67	Value . . .	734
1851	93	" . . .	789

West Chiverton was another important mine in this neighbourhood, and commenced selling lead ores in 1859; the following were its most productive years:—

Year.	Ore.	Lead.	Silver.
	Tons.	Tons.	Oz.
1866	3,166	1,970	66,950
1867	4,082	3,061	130,624
1868	4,516	3,387	144,512
1869	4,707	3,529	150,504
1870	4,777	3,582	161,190

In 1881 its production only amounted to 177 tons 3 cwts. of lead ore, containing 1,747 oz. silver, and having an aggregate value of £2,120; in 1885 it was only 31 tons valued at £155, and its career seems to have come to a close with a production of 3 tons in 1886.

In this section of the county there are also lead veins at Swanpool and Pennance, near Falmouth, and others near Porthleven south-west of Helston.

Park of Mines is situated three miles south of St. Columb on the west side of the road leading from that town to Truro, and has at various times yielded a considerable amount of tin ore from deposits of a somewhat unusual character.[1] The enclosing rock is killas, which may here be defined as a gray, buff, or white indurated schist, dipping at an inclination varying from 30° to 80° in a general northerly direction. The north-western corner of the great granite range which lies to the north of St. Austell extends to within three-quarters of a mile of this mine. Numerous small veins, generally dipping east, traverse the killas from north to south, and usually vary in width from the thickness of a common table-knife to a quarter of an inch. These are mainly composed of quartz, but the killas for a distance of from half an inch to two inches on each side has been blackened and hardened by an impregnation of schorl.

The tinstone of the Park of Mines has apparently been derived

[1] C. Le Neve Foster, *Miners' Association of Cornwall and Devon*, 1875, p. 22.

from lateral offshoots of the north and south veins, as in the proximity of these strings lenticular masses of tin ore occur interposed between the bedding planes of the killas.

The mode of occurrence of the tinstone at Park of Mines will be best understood by referring to the annexed diagrams. Fig. 69

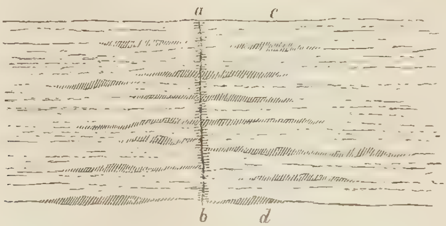


Fig. 69.—Horizontal section, Park of Mines.

represents, in horizontal section, a north and south vein, *a b*, as seen at the twenty-fathom level, with layers of tinstone which rarely extend for a distance of more than six feet on each side of it. Fig. 70 is a vertical section on the line *c d*, showing the beds of killas dipping north at an angle of 70°, with interposed lenticular masses of tin ore. The stanniferous zone in this particular case extends about seven fathoms from north to south, and ten fathoms along the line of dip. The lenticules of tin ore do not usually exceed two inches in thickness at their widest part, the whole mass of killas and tinstone being consequently worked away together and sent to the surface to be stamped and dressed. Occasionally the thickness of tinstone reaches nearly a foot, the only minerals associated with it being schorl, quartz, and kaolin. The killas near the boundary of the stanniferous layers is usually stained by oxide

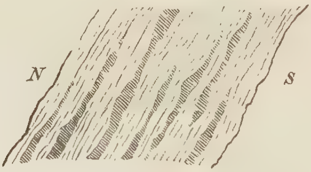


Fig. 70.—Vertical section, Park of Mines.

of iron, and consequently red killas is regarded by the miners as a favourable indication of their near approach to a deposit of tinstone. This may be classified as a group of very small bedded veins, or as lenticular masses intercalated in the killas and connected with the neighbouring granitic rocks. The workings of this mine, which extend over an area of about an acre only, have been prosecuted to a depth of about forty-five fathoms. In 1874 the Park of Mines yielded 231 tons of black tin.

The production of ores from mines in the West Central Division of Cornwall was as follows during the year 1881:—

	Weight. Tons.	cwts.	qrs.	Value. £	s.	d.
Black tin	9,088	16	0	504,376	3	11
Copper ore	11,243	13	0	39,288	1	5
Lead „	297	0	1	3,268	10	0
Zinc „	7,792	17	3	23,565	2	0
Silver „	1	12	2	175	0	0
Iron „	3,257	0	0	1,869	10	0
Iron pyrites	957	3	0	467	3	6
Wolfram	49	5	0	495	8	0
	32,687	7	2	573,504	18	10

East Central Division.—The St. Austell mining district comprehends the whole of the St. Stephens and Hensbarrow range of granite, together with a band of killas surrounding it on all sides, averaging in width about three miles. On the south this district is bounded by the sea, extending from the Black Head to Tywardreath, on the west to St. Denis, on the north nearly to Bodmin, and on the east to Lostwithiel. It comprises parts of the parishes of St. Ewe, St. Mewan, St. Austell, St. Blazey, Tywardreath, Lanlivery, Lanivet, Luxulyan, Roche, St. Denis, and St. Stephens. The mass of granite, which is here very large, exhibits the same characteristics as those of the western districts, and frequently contains much schorl. This neighbourhood supplies nearly the whole of the china clay and china stone sent from Cornwall to the Potteries, or which is exported to other countries. This district was formerly very productive for both tin and copper, but at the present time all the principal copper mines have been suspended, and Huel Eliza, a mile and a half east of St. Austell, was in 1882 the only rich tin mine working in this part of the county. Small quantities of tin are, however, still annually obtained from the granite in what is known as the St. Austell-Moor district. The once celebrated tin mines of Polgooth and Hewas were worked in the belt of killas a little south-west of the town of St. Austell, while in the same rock, to the east, were the tin mines of Bucklers and the copper mines of Pembroke, East Crinnis, Mount, and Fowey Consols, all of which have long since ceased working upon any extensive scale. The well-known tin mine of Beam, situated in the granite, is no longer in operation, and the great open cutting at Carclaze is worked chiefly for china clay.

The granite throughout this district is traversed by innumerable schorlaceous veins, which, although generally very small, almost invariably contain a certain proportion of tin oxide. The tin ore is, however, seldom confined exclusively to such veins, but is generally disseminated throughout the substance of the contiguous rock, into which, although the line of separation is usually distinguishable, the veins frequently pass by imperceptible gradations. The killas of this district is fine-grained, with a silky lustre, and schistose structure. Its colour is usually blue, varying considerably in intensity, while its prevailing dip is towards the south-east. In many places it abounds with beds and veins of white quartz. Dykes and irregular patches of an altered doleritic rock, now represented by various greenstones, penetrate the slates of many parts of this district. Elvan occurs in the sea-cliff of Polruddan, and extends through Hewas Mine to beyond Tolgarrick, in the parish of St. Stephens. At Stennagwyn, in that parish, there is a remarkable impregnation of the granite with tin ore, of which a portion is in the form of tin sulphide or *stannite*. A small quantity of black tin has on various occasions been obtained from this locality, but the whole of the stannite is lost during the operation of dressing.

The direction of the lodes in this neighbourhood is usually a few degrees S. of W., but there are others which bear nearly S.E. and N.W., thus closely approximating to the direction of the counter lodes in the western parts of Cornwall. There are but few cross-courses or cross-flucans in the district ; but at Polgooth a flucan heaves the lodes and elvan a distance of thirty fathoms, and in the same mine the St. Martins and Screeds Lodes both appear to be displaced by an elvan course, a phenomenon which is believed to be without parallel in the mines of the county.

At Restormel, near Lostwithiel, there is a large iron lode bearing about 15° W. of N., and dipping E. 75°. It varies from two to four fathoms in width, and is generally divided into two branches by a band of slate. Workings have been extended on the course of this lode for a distance of nearly two miles, but their depth is generally inconsiderable. The chief produce of this vein is hæmatite, with a little black oxide of manganese, while göthite, associated with quartz, occurs as crystals lining numerous druses disseminated throughout the veinstone. The shoots of ore met with in the neighbourhood of St. Austell usually dip from the granite.

Sixty years ago among the most prosperous and well-managed copper mines in the killas of this district were those of Fowey Consols, situated in the parish of Tywardreath. The lodes in this locality are much contorted in length and depth, and are remarkable for the number of junctions they make with one another in their downward course. The enclosing killas, which is of a pale blue colour, alternates with bands of felsite, while the veinstone is principally composed of milk-white quartz, often enclosing angular fragments of the country rock. Iron pyrites and spathose iron ore are frequent constituents of these lodes; the other minerals present being various ores of copper, with bismuthine, the latter occurring in larger quantities in this mine than in any other locality in Cornwall. The extent of these mines is very considerable, since some of the lodes are believed to run through the sett for a distance of above a mile. From August 1815 to the end of the year 1841, these mines returned 234,486 tons of copper ore, which sold for £1,442,683, and out of this amount the profit paid to the shareholders was £179,995, leaving a large reserve fund not divided. The estimated value of plant and machinery was, in the latter year, about £55,000, but shortly after this date the annual produce gradually fell off, and the mines were finally abandoned in 1868. The year of their greatest production was 1838, when they yielded 15,254 tons of copper ore, produce $9\frac{6}{8}$, value £85,434.

This region once afforded a larger supply of stream tin than any other part of the county, but the more extensive stream-works, such as the Happy Union at Pentewan, Huel Virgin in the St. Austell Valley, and those in the vicinity of the Jamaica Inn, being all exhausted, none of this class of tinstone is now obtained from the district.

The tin streams of Cornwall have been long known to afford occasional specimens of gold, but not in sufficient quantities to make its collection a matter of any importance.[1]

Various lodes yielding small quantities of lead and copper ores have, from time to time, been, to some extent, explored in the tract of country extending along the north coast from St. Columb to beyond Camelford; but although small bunches of ore have

[1] In his *Survey of Cornwall*, 1602, Richard Carew says, "Tynners doe also find little hoppes of Gold amongst their Owre, which they keepe in quils, and sell to the Goldsmithes oftentimes with little better gaine than *Glaucus* exchange."—Book i. p. 7.

occasionally been found, no adequate results have yet been obtained for the money expended.

A highly interesting mine is the Uranium Mine at Grampound Road in the Parish of St. Stephens, which commenced operations about the year 1889. It traverses killas [1] through which patches of greenstone occur; some 500 yards to the east the killas has been subjected to sufficient pressure to produce fairly good roofing slates. About half a mile to the north-east from this sett is the boundary of the granite and china-clay district. A number of veins are known in this district, several being tin, one of which promises to be of some value, and also an elvan course impregnated with a small percentage of the same metal.

A deposit of iron ore, chiefly magnetite, also occurs here, and there are some patches of tin ore in connection with it. The vein that carries the uranium ores is a fissure vein striking north and south, and having a very small dip to the west; its thickness varies from one to three feet. The country rock is a light bluish coloured killas, but greenstone was met with at a depth of twenty fathoms. From the surface to the adit level, some seven or eight fathoms below the outcrop, the vein was filled with a ferruginous gossan with earthy uranium ores of variable composition, but consisting largely of the uranates of lime and copper. Below adit level the vein became much harder, the gangue consisting chiefly of quartz coloured with oxide of iron, and the earthy ores were replaced by pitchblende. Occasionally small bunches of copper ores and galena were found, the latter being argentiferous. The lode has been opened up for a length of sixty fathoms and to a depth of twenty fathoms. The ores were hand-sorted into two qualities,

No. 1 containing 20 to 25 °/ₒ uranium oxide.
No. 2 „ 5 to 10 °/ₒ „ „

This is the only mine in Great Britain worked exclusively for uranium oxide. Its output has been as follows:—

Year.	Quantity. Tons.	Value. £
1890	22	2,200
1891	31	620
1892	37	740
1893	25	500
1894	19	815

The total production of the mines of the East Central Division

[1] For information concerning this mine I am indebted to Mr. W. R. Thomas, who was for some time its manager.—H. L.

of Cornwall during the year 1881 was, according to published statistics, as follows :—

	Weight. Tons.	cwts.	qrs.	Value. £	s.	d.
Black tin	658	15	3	38,566	16	0
Copper ore	134	8	0	581	7	3
Silver „	4	6	1	183	7	0
Iron „	4,203	0	0	2,572	1	0
Totals	5,000	10	0	41,903	11	3

Eastern Division.—The mines of the Caradon district are chiefly included in the parishes of St. Cleer and Linkinhorne, and are situated in a granitic area forming, for the most part, the southern border of the Bodmin-Moor mass of granite, but including also its southern and south-eastern junction with the killas. This formation is here much intermixed with hornblendic rocks, while both it and the granite are occasionally traversed by courses of elvan. In addition to the slaty rock thus skirting the granite, a tract of slate nearly a mile in length and having somewhat less than half that width, a little to the south-east of the Cheesewring, is represented as being completely surrounded by granite. That this comparatively small patch of killas is, to a very large extent, encircled by granite, appears to be certain; but that it is completely severed from the great body of sedimentary rocks lying to the east has never been conclusively proved. Within the boundaries assigned to this area of killas, the hanging wall of the Phœnix Lode, to a depth of thirty-five fathoms from the surface, consists of slate, while the foot wall is wholly of granite; but at all greater depths both walls are composed of granite. The shallower parts of various other lodes in this immediate neighbourhood are also bounded by slate on their south side and by granite on the north; the same is the case at Sharp Tor, north of Phœnix. At Marke Valley, three-quarters of a mile to the south-east, the lode, which dips towards the north, has slate as its hanging wall to a depth of thirty-six fathoms, while the foot wall is of granite; but at all greater depths the walls on both sides are of granite. The slate which forms the hanging wall of the Phœnix Lode, to a depth of thirty-six fathoms, is very quartzose, but contains flakes of mica, with a few fragments of felspar, and occasional needles of schorl. Its colour is pink, buff, or light gray, but it is sometimes mottled with spots of crimson or of brick red; it is often coarse-grained, and is occasionally much contorted.

The outcrops of the lodes on the southern slope of the granitic range at West Caradon and South Caradon, consist of soft pale-brown or reddish-brown gossan, with friable quartz, decomposed granite, chlorite, and a little fluor spar. Where the structure is cellular, nests of clay, black oxide of copper, and malachite often occur, as well as small patches of iron pyrites, mispickel, and various ores of copper, together with cuprite, and small plates and ramifications of native metal. In the deeper portions of the same veins, quartz, felspar, and chlorite, with occasional masses of granite, are still the chief constituents; but brown iron ore, although sometimes present in small quantities, is less plentiful, while fluor spar becomes more abundant. At the same time the copper glance, cuprite, malachite, and black oxide of copper gradually disappear in depth, while the quantities of fluor spar and copper pyrites increase. These lodes contain no appreciable amount of tin ore. At Stowes, Phœnix, South Phœnix, Dunsley Phœnix, and Marke Valley, the lodes have, besides ores of copper, afforded tin ore, but contain no fluor spar; those of the Caradon Mines, on the contrary, have yielded large quantities of copper ore, and contain much fluor spar, but give little or no tin.

Several of the principal lodes in this district afford abundant evidence of the original fissure having again opened, subsequently to its becoming more or less completely filled with various crystalline minerals. The great lode at the Phœnix Mines may be cited as an example of a vein of which the constituents were deposited during two perfectly distinct periods. The first formation was stanniferous, and was attended with the production of capels; the second mainly consisted of quartz, associated with various ores of iron and copper.

One of the lodes at South Caradon has in the same way resulted from a kind of double deposition. In this case the first formation is rich in copper ores, while the second is composed chiefly of drusy quartz, with fluor spar and iron pyrites.

Three of the principal mines in the Caradon district yielded copper ores to the following amounts and values, during the several periods stated in the following table:—

					Tons.	£
South Caradon—ten years to end of				1861	41,790	429,551
,,	,,		,,	1871	60,794	491,782
,,	,,		,,	1881	57,389	361,413
West Caradon	,,		,,	1861	39,464	342,684
,,	,,		,,	1871	13,341	79,988
,,	,,		,,	1881	1,663	5,936
East Caradon	,,		,,	1871	39,091	194,926
,,	,,		,,	1881	10,425	53,494

During the year 1881 these mines made the following returns respectively:—

	tons	cwts.	£	s.	d.	Produce.
South Caradon	5,185	9	27,609	3	2	$9\frac{1}{4}$
West Caradon	227	3	804	14	6	$6\frac{3}{4}$
East Caradon	118	19	533	16	8	$7\frac{3}{4}$

In 1883 South Caradon was still a large producer, its output having been 3,016 tons worth £13,725, but from this date it commenced to decline rapidly; in 1886 its output was only 162 tons worth £83, and after that this group of mines appears to have closed down completely.

The lead veins of the neighbourhood of Liskeard are situated in the parishes of Lanreath and St. Pinnock, three and a half miles S.W. of the town, and seven miles from the Caradon granite; and in the parish of Menheniot, about one and half mile S.E. of Liskeard, the latter district extending from Butterdon, near the Callington turnpike, to within half a mile of Menheniot Church. The Lanreath and St. Pinnock district is a very small one, being scarcely a mile long, by one-eighth of a mile in width. Its only important mine is Herodsfoot, which was the first mining work undertaken in the neighbourhood of Liskeard. The Menheniot lead district is about a mile and a half in length and half a mile in width; its principal mines being Huel Mary Ann and Huel Trelawny.

The Lanreath and St. Pinnock Mines lie a little west of the imaginary boundary line, and, therefore, belong, strictly speaking, to the East Central Division of the county; as, however, this district adjoins that of Menheniot and resembles it in many respects, it will be more convenient to describe them together.

The rocks of both these districts chiefly consist of slates, sometimes enclosing Devonian fossils, and near the surface are generally brown, drab, or dun-coloured, but at greater depths have a silky lustre and assume a deep blue or blackish hue.

At various depths in the mines of Huel Trelawny and Huel Mary Ann the ordinary killas has, lying between its planes of bedding, conformable sheets of felspathic and hornblendic rocks, which are locally known as elvans, and are usually massive, but sometimes exhibit a schistose structure. Between these and the slate there is sometimes a gradual change, but more commonly the transition from one to the other is distinct and immediate. The felspathic and hornblendic rocks of this neighbourhood occasionally contain spheroidal bodies made up of many concentric layers. This structure is not, however, entirely confined to the hornblendic and felspathic rocks, since Henwood states that at

Huel Trelawny a concretion of this kind, consisting of five distinct layers of quartz and galena, was found in a siliceous slaty matrix at a depth of fifty-five fathoms from the surface.

In neither of these districts has more than one productive lode been discovered. That upon which the Menheniot mines have been opened takes somewhat different directions in various parts of its course, its bearing in Huel Trelawny being 5° W. of N. and E. of S., while in Huel Mary Ann its course is from 3° to 8° E. of N. and W. of S. In the Lanreath district the lode at Herodsfoot bears from 8° to 12° W. of N. and E. of S.

The lodes of this region maintain an average dip of 79°, their inclination being to the east; in thickness they vary from six inches to four feet, the average width being probably about two feet. The chief constituent of the lodes in both districts is quartz, which, near the surface, is often granular, and is mixed with ferruginous gossan, but at greater depths is generally massive and milk-white in colour. In the Menheniot Lode chalcedonic silica is sometimes associated with vitreous quartz and chalybite, while calcite occurs in the deeper levels. At Herodsfoot, pearl spar is found in the joints and crevices both of the lode and of the country rock. Iron pyrites, which is usually more or less argentiferous, is a common constituent of both lodes, while small quantities of chalcopyrite and blende occur most frequently in the more quartzose portions of the veins. In addition to these minerals, the lode at Herodsfoot contains bournonite and sulphide of antimony. Carbonate and phosphate of lead occur near the surface, but lower down these minerals are entirely replaced by galena. In the Menheniot Lode the ore is often associated with quartz and fluor spar; while at Herodsfoot, on the other hand, a granular quartzose veinstone, including numberless spots and patches of galena, is traversed by strings and ribs of that ore. In this, as in all other lead districts, the ores obtained from different lodes, and even from different parts of the same lode, are unequally argentiferous. The ore sold at Huel Trelawny from 1851 to 1869 afforded on an average 0·001246 its weight of silver, which is equivalent to 40 oz. 13 dwt. 9 gr. per ton of 2,240 lbs.

At Huel Mary Ann the ore returned from 1851 to 1869 yielded on an average 0·001435 of silver, equal to 46 oz. 17 dwt. 11 gr. per ton. In both mines there was a gradual increase in the proportion of silver from the shallower to the deeper levels. Huel Mary Ann and Huel Trelawny suspended operations in 1876.

The lead ore extracted from the northern and southern mines at

Herodsfoot from 1851 to 1867 afforded on an average 0·000814 of silver, equivalent to 26 oz. 11 dwt. 16 gr. per ton. The lead ores raised throughout Cornwall in 1855 contained on an average about 23 oz. of silver per ton.

The lodes of this district frequently enclose thin laminæ of slate, which usually assume the direction and dip of the enclosing veins. These fragments are often sharply defined and quite unaltered, but they are sometimes permeated by siliceous and calcareous matter, or are penetrated by strings and branches of veinstone. The leaders or metalliferous portions of the veins are sometimes separated from the country rock by a band of breccia, consisting of angular masses of slate sometimes enveloped in as many as six accretions of chalcedonic silica. These enclosed fragments are often exceedingly small, and seldom exceed three inches in diameter; they have frequently to some extent become replaced by quartz, and thin branches of this mineral, containing either galena or iron pyrites, often intersect or interlie the laminæ. Cavities studded with botryoidal concretions of agate-like silica encrusted with crystals of quartz and sprinkled over with calcite and chalybite occur in all parts of the siliceous cement.[1]

Towards the southern portion of Huel Mary Ann and throughout the adjoining mine of South Huel Trelawny as well as between the old and new mines at Herodsfoot, the lodes are represented by bunches and disconnected strings of veinstone, occasionally containing a few spots and bunches of ore. These usually follow a joint maintaining the normal direction of the lode, but seldom affect parallel portions of neighbouring joints. Wherever the lodes are thus broken up and disturbed, the country rock is disordered and traversed by numerous flucans of slaty clay.

The workings at Herodsfoot were extended, at different depths, for distances varying from thirty to forty-five fathoms through this disordered ground, before the lode, which had dwindled in the old mine, was again found in the new. At Huel Mary Ann and South Huel Trelawny still greater distances were laid open without success. The water of these mines contains large quantities of sulphate of calcium.

The Menheniot lead lode is intersected by two flucans, the most northerly of these, in Huel Trelawny, bears 10° S. of E. and dips

[1] Fig. 41, p. 91, shows the mode of occurrence of brecciated veinstone at Huel Mary Ann, while Fig. 38, p. 88, represents a quartzose concretion from Huelgöet of the same character as those which are found in the cementing material of the Menheniot lodes.

S. about 55°; the more southerly, in Huel Mary Ann, bears about S.E. and N.W., with a dip N.E. varying from about 40° to 50°. The lode has consequently the direction of the unproductive cross-courses of other districts, while the flucans have the same bearing as the lodes of tin and copper.

According to Henwood the profits made from 1844 to 1869 were as follows:—

Huel Trelawny	£56,914
Huel Mary Ann	65,585
Herodsfoot	49,848
Total . .	£172,347

At Huel Ludcott, in the parish of St. Ive, about a mile and a half N.N.E. of Huel Trelawny, the country rock is a glossy dark-blue killas, with planes of cleavage ranging nearly N.E. and S.W. and dipping from 15° to 20° S.E. Two nearly parallel lodes running about N. and S., and dipping from 80° to 86° E., have been worked, one to a depth of 80 and the other to that of 130 fathoms. The shallower parts of both veins consisted of granular quartz, gossan, and slaty clay, with, occasionally, a little iron pyrites, chalcopyrite, blende, and galena. At more considerable depths the quartz became less crystalline, and calcite made its appearance. In some places both these lodes, which vary from two to three feet in width, were rich in galena, which, on one side of the north cross-course, contained nearly twice as large a proportion of silver as on the other. Three cross-veins, all bearing E. and W., dipping S., and varying from one foot to eighteen feet in width, intersect both lodes.

The cross-veins generally consist of slaty clay, granular quartz, calc spar, chalybite, and iron pyrites; but sometimes the quartz becomes more flinty, and isolated masses of galena or small patches of copper pyrites make their appearance. Between the severed portions of the eastern lode, at depths varying from 93 to 110 fathoms, the northern cross-course enclosed crystals of galena poor in silver, occasionally detached, but sometimes embedded in masses of argentite of considerable size. Stephanite, pyrargyrite, and argentite were also met with in druses, where they were sprinkled over crystals of quartz and calcite. Crystals of galena were also often covered in the same way with crystals of silver ore, and threads of native silver traversed the veinstone as well as the galena and other ores. From this cross-course

304 tons 15 cwts. of silver ores were obtained, which sold for a little more than £22,501, making an average of £73 16*s.* 3*d.* per ton. The percentage of lead varied from 7 to 40 per cent., but the average yield of this metal was not much above 9 per cent., and the ores can, therefore, only be regarded as silver ores.

The Callington mining district may be described as an area chiefly consisting of clay slate, which includes the two smaller granite protrusions of Kit Hill and Gunnis Lake, constituting links between the two great ranges of Bodmin Moor and Dartmoor. It comprises parts of the parishes of Callington, Calstock, and Stoke Climsland, including an area of about five miles in length and nearly three in width.

The granite of Kit Hill and of Gunnis Lake is somewhat finer in grain than that of the larger masses of that rock further west, but it is frequently traversed by veins of quartz and schorl, which sometimes contain tin oxide. The slate varies considerably in different localities, both in colour and in texture. At Drake Walls, where it is of a deep blue colour and has a silky lustre, several lodes have been worked, and have in the aggregate produced large quantities of tin ore, which is, however, usually associated with wolfram. The rock is often traversed by small veins of cassiterite, like those which occur in slate at Polberrow, and in granite at Carclaze, and elsewhere in Central Cornwall. The direction of the lodes is generally a few degrees S. of W.; but some of them bear rather N. of W. They dip for the most part towards the north, although a few have an opposite inclination. Cross-courses are numerous, and they occasionally heave the lodes to a considerable distance. Huel Betsy and Redmoor, which are both in killas, have yielded large quantities of galena associated with chalybite. Native copper, cuprite, malachite, black copper, copper glance, copper pyrites, and sundry rare minerals, and among others uranite, have been found at Gunnis Lake.

A metalliferous bed containing quartz, chalybite, copper pyrites, and other minerals occurs at Virtuous Lady. Its course is about 20° S. of W., and its dip N., with a thickness varying from a few inches to thirty feet. The ores, which are very irregularly disseminated throughout the mass, usually occur in the quartz, but large patches are also sometimes found associated with carbonate of iron and iron pyrites. This mine was long celebrated for its fine crystals of chalybite. Childrenite has been found at the George and Charlotte Mine, as well as at Huel Crebor, in this district.

The Callington district at the present time is of but little commercial importance as a mining area, although it was formerly much more productive. The mine till recently making the largest returns is Gunnis Lake Clitters, which, during the year 1881, yielded 2,520 tons of copper ore, of the value of £15,831 15*s.* 6*d.* It is now closed down. An attempt was recently made to re-open Callington Mine and to work the arsenical pyrites that had been previously neglected as worthless, but after struggling on for a couple of years it was again closed down.

The production of the mines of the Eastern Division of Cornwall, during the year 1881, was as follows :—

	Weight.			Value.		
	Tons.	cwts.	qrs.	£	*s.*	*d.*
Black tin	541	13	1	29,958	8	0
Copper ore	11,941	17	0	56,390	16	10
Lead "	467	17	1	4,550	7	10
Iron pyrites	13,953	6	0	13,154	16	11
Wolfram	5	2	2	48	13	9
Totals .	26,909	16	0	104,103	3	4

In addition to the black tin produced by the mines of Cornwall during the year 1881, 957 tons 1 cwt. were obtained from streams, rivers, and foreshores, and 263 tons 19 cwts. 2 qrs. of black tin were returned as sold in the form of undressed tin-stuff. In 1894 the so-called stream works, the largest of which are on the Red rivers, and which treat the tailings from the various mines, that is to say re-treat the refuse which the tin stamps allow to run to waste, extracted 1,300 tons of tin ore valued at £29,075. That dressing operations should be so carelessly conducted as to allow of the tailings becoming a source of profit to those who have not incurred any of the expense of raising the ore, and to admit of so large a quantity of metal being extracted from them, has long been a disgrace to Cornish tin-mining, and cannot but have contributed in some measure to the present unfavourable condition of that industry.

Cornwall has been a small producer of iron ore up to the year 1883, when its output of that mineral practically ceased, Restormel and Lostwithiel appearing to have been two of the most important localities for it. The production from 1855 to 1865 averaged from 25,000 to 30,000 tons per annum, though it was as high as 55,000 in 1858. From 1866 to 1871 the annual production was under

10,000 tons, but it reached 48,000 again in 1872; it then commenced to decline rapidly, though with occasional spurts, till it was only 950 tons in 1883. It is not to be supposed that the iron deposits of Cornwall are exhausted, indeed the contrary is known to be the case, but as long as good ores can be sent in from Spain and other places, where they can be quarried opencast, there is little hope for vein mining for iron ores in Cornwall.

Statistics Relating to the Production of Tin, Copper and Lead Ores, and Arsenic in Cornwall.—The period at which Cornish tin was first worked and exported has been lost in the obscurity of ages. According to Borlase, however, the production of tin in Cornwall was very inconsiderable even in the time of King John, 1199-1216. In this reign the tin farms of the county yielded no more than 100 marks per annum, and in accordance with this valuation the Bishop of Exeter received, in lieu of his tenth part, the sum of £6 13*s.* 4*d.* The tin farms of Devonshire, at the same period, yielded £100.

In 1750 the production of the Duchy of Cornwall was 18,698 blocks, equivalent to about 3,132 tons of metallic tin. In 1800, after having been in 1789 as high as 22,132 blocks, the production was 16,397 blocks, or about 2,746 tons. The production of metallic tin in the year 1838, after having been as high in 1827 as 31,744 blocks, amounted to 29,321 blocks, or about 4,911 tons.

Until the year 1854 the production of the Cornish tin mines was by the Mining Record Office grouped with that of Devon, although the yield of the latter county was relatively unimportant. The table on the next page gives the production of tin in Cornwall from the date at which records of the yield of the two counties have been kept separate.

The largest production of tin ore in Cornwall was in the year 1871, but since 1873 the amount annually produced has not very materially fluctuated, though the last few years show a little falling off in quantity and a marked depreciation of values owing to the low price of tin.

Copper mines do not appear to have been worked in this county until about the year 1700, although small quantities of copper ore were previously obtained from mines worked more expressly for tin. In 1838 the production of the copper mines of Cornwall amounted to 145,688 tons, each of 21 cwts.,[1] representing a money value of £857,779.

[1] Copper and lead ores are sold by the ton of 21 cwts.

Weight and Value of Tin Ore obtained from Cornish Mines from 1854 to 1894.

Year.	Tons.[1]	Value of Ore.	Remarks.
		£	
1854	8,447	540,608	
1855	8,627	586,636	
1856	9,214	764,762	
1857	9,688	736,228	
1858	9,905	630,328	
1859	10,059	723,370	
1860	10,225	798,209	
1861	10,725	775,612	
1862	11,638	773,729	
1863	13,932	924,447	
1864	13,667	861,345	Production of Cornish mines
1865	13,867	767,680	and tin streams for ten
1866	13,601	658,686	years to end of 1871—
1867	10,988	545,238	
1868	11,530	638,052	Tons. Value.
1869	13,756	879,997	134,928 £8,105,313
1870	15,190	998,963	
1871	16,759	1,057,176	
1872	12,156	1,053,001	
1873	14,660	1,034,693	
1874	14,686	746,328	
1875	13,800	690,592	Ten years to end of 1881—
1876	13,523	570,996	
1877	14,395	557,295	Tons. Value.
1878	14,992	519,581	138,521 £7,098,129
1879	14,168	559,242	
1880	13,353	673,380	
1881	12,788	693,021	
1882	13,994	803,195	
1883	14,399	731,492	
1884	15,091	668,151	
1885	14,323	659,935	Ten years to end of 1891—
1886	14,124	774,342	
1887	14,083	872,205	Tons. Value.
1888	14,282	888,940	143,363 £7,637,236
1889	13,756	726,240	
1890	14,868	780,017	
1891	14,444	732,719	
1892	14,260	728,933	
1893	13,637	634,274	
1894	12,880	486,150	

On referring to the table on opposite page it will be seen that the annual production of the county has gradually decreased since 1855.

It will be observed that the production of copper ore in 1894 represented only one-hundredth, and in 1881 only one-tenth of the value of that raised in 1855. The average produce in metal of

[1] The ton of tin ore consists of 20 cwts. each of 115 lbs.

the copper ores of Cornwall is at present about $6\frac{5}{8}$, although in 1848 it was as high as $8\frac{3}{8}$.

WEIGHT AND VALUE OF COPPER ORE OBTAINED FROM CORNISH MINES FROM 1855 TO 1894.

Year.	Tons.[1]	Value.	Remarks.
		£	
1855	161,576	1,064,474	Production for seven years to end of 1861— Tons. 1,060,164; Value. £6,532,512
1856	163,958	1,019,176	
1857	152,729	979,565	
1858	147,330	873,347	
1859	146,093	905,897	
1860	145,359	873,471	
1861	143,119	816,582	
1862	141,810	728,299	Production for ten years to end of 1871— Tons. 973,494; Value. £4,585,017
1863	129,221	642,944	
1864	127,033	659,918	
1865	121,353	572,619	
1866	103,670	431,083	
1867	88,603	413,533	
1868	86,722	373,005	
1869	71,790	316,364	
1870	56,526	242,227	
1871	46,766	205,025	
1872	41,756	226,654	Production for ten years to end of 1881— Tons. 362,619; Value. £1,670,614
1873	40,285	188,236	
1874	40,455	201,367	
1875	39,393	204,228	
1876	43,016	202,203	
1877	39,225	169,549	
1878	36,871	146,413	
1879	30,371	116,168	
1880	26,737	111,408	
1881	24,510	104,388	
1882	25,641	114,688	Production for ten years to end of 1891— Tons. 122,509; Value. £428,847
1883	23,252	87,394	
1884	21,541	65,582	
1885	19,736	51,143	
1886	7,541	20,245	
1887	3,422	10,149	
1888	6,841	37,258	
1889	4,962	15,569	
1890	5,273	15,345	
1891	4,299	11,474	
1892	2,813	6,359	
1893	2,673	6,600	
1894	3,370	10,802	

The table on following page shows a great falling off since 1845 in the quantity and value of the argentiferous lead ores annually produced in the county of Cornwall.

[1] Copper and lead ores are sold by the ton of 21 cwts.

Weight of Lead Ores obtained from Cornish Mines from 1845 to 1886, with the Amounts of Lead and Silver respectively contained in them, &c.

Year.	Lead Ore.	Lead.	Silver.	Value of Ore.
	Tons.	Tons.		
1845	10,100	6,063		
1846	11,574	7,304		
1847	8,228	4,933		
1848	10,494	6,614		
1849	10,325	6,773		
1850	10,386	6,782	Oz.	
1851	9,515	6,709	255,640	
1852	8,998	6,220	250,008	
1853	6,680	4,690	165,670	Average per ton.
1854	7,460	5,005	179,675	£ s. d.
1855	8,962	5,882	211,348	14 4 6
1856	9,973	6,597	248,436	14 8 0
1857	9,559	6,036	224,277	14 15 0
1858	9,710	5,436	223,189	14 6 0
1859	7,842	4,985	215,964	13 16 0
1860	6,410	4,242	180,757	13 17 8
1861	6,690	4,228	173,344	12 10 7
1862	6,030	4,119	205,662	12 10 0
1863	6,259	4,270	206,312	13 1 6
1864	5,301	3,538	192,232	14 5 10
1865	6,546	4,296	214,659	12 14 7
1866	6,736	4,350	195,218	12 15 1
1867	8,645	6,480	314,326	12 17 6
1868	8,415	6,310	303,033	12 1 8
1869	9,023	6,775	315,714	12 5 6
1870	8,481	6,360	292,045	12 4 6
1871	7,564	5,073	267,324	12 6 0
1872	5,463	4,098	207,710	13 13 0
1873	3,909	2,923	129,509	15 8 0
1874	3,119	2,337	85,304	14 13 6
1875	2,566	1,932	25,681	15 9 3
1876	2,727	2,070	37,650	15 8 0
1877	2,166	1,674	23,035	13 19 0
1878	1,349	1,022	16,456	10 11 8
1879	725	545	9,435	10 6 0
1880	754	570	11,790	11 6 0
1881	765	409	14,396	10 3 0
1882	624	454	11,460	11 0 6
1883	830	588	9,445	9 11 3
1884	529	352	5,000	7 2 10
1885	241	160	2,500	8 6 0
1886	227	168	2,200	8 5 0

There has been practically no lead produced in the Duchy since 1886.

	Tons.
Total production of lead ore for ten years to end of 1861	82,284
,, ,, ,, ,, 1871	73,000
,, ,, ,, ,, 1881	23,543
,, ,, from 1881 to end of 1894	2,467

The production of white arsenic by the calcination of arsenical pyrites has long been an important industry in Cornwall. It seems to have been at its best in 1884 and 1885, and has been slowly falling since that time. The following table shows the returns since the first-named date; in 1884 and 1885 the production of arsenical pyrites is included in the returns of arsenic.

PRODUCTION OF ARSENIC IN CORNWALL FROM THE YEAR 1884 TO THE YEAR 1894.

Year.	White Arsenic.		Arsenical Pyrites.	
	Quantity.	Value.	Quantity.	Value.
	Tons.	£	Tons.	£
1884	4,273	24,062	—	—
1885	4,034	27,499	—	—
1886	1,791	9,671	2,414	5,898
1887	1,661	10,122	102	97
1888	1,584	9,295	1,443	1,154
1889	1,927	12,110	2,443	2,453
1890	3,143	26,503	1,536	1,681
1891	3,048	26,423	1,104	1,234
1892	2,567	19,600	1,086	1,067
1893	1,751	13,471	835	639
1894	1,853	16,166	1,516	1,340

DEVONSHIRE.—The mines of Devonshire are much less numerous and productive than those of Cornwall, which they, however, resemble in various other respects, besides being for the most part situated in the approximate vicinity of the junction of clay slates and granite. The most important of the mining districts of this county is that of Tavistock, which includes the whole of the killas area extending from the river Tamar to Dartmoor, having a width from north to south of about ten miles. In this district are situated the celebrated copper mines of Devon Great Consols, formerly the most productive in Great Britain. This undertaking was started in the year 1844 with a capital of only £1,024, which was never increased by calls or otherwise; but in the course of the following twenty-one years a total profit of £1,000,000 was the result of the operations.

The mining field of Devon Great Consols comprehends several separate grants, all of which are connected by underground workings. The original sett was that of Huel Maria, the others having been subsequently added as extensions became desirable. There are six different lodes at the Devon Great Consols, namely, two to the north of the main lode, the main lode itself, and three others to the south of it; these, including the principal vein, have a direction varying from 12° to 20° S. of E. and N. of W. Their underlie is towards the S., and is on an average about two feet in a fathom.

The country rock is a kind of mottled killas, the spots in which are apparently caused by minute and imperfect crystals of andalusite. At one point the workings extend westward to the Gunnis Lake mass of granite, but there are no elvans in the immediate neighbourhood of the mines. In the greater portion of the workings the walls of the lodes are well defined, this being more especially the case where they are most productive. The width of the main lode, which has yielded the principal portion of the copper obtained from the mines, is sometimes as much as thirty feet; while the others are considerably narrower and of less importance. There are ten known cross-courses at Devon Consols; one at Huel Maria has heaved the lode eighty fathoms to the right, but the other lodes have not been opened sufficiently near this cross-course to ascertain its influence upon them. What is known as the "Great Cross-course" is chiefly composed of flucan, with occasionally a little gossan near the surface. Spots of lead ore have also occasionally been found in the flucan. The lodes are, for the most part, composed of quartz associated with iron pyrites, arsenical pyrites and copper pyrites, with sometimes a little tin ore, while carbonate of iron is usually present, not unfrequently forming the material cementing together the brecciated portions of the veins. One of the lodes in these mines sometimes assumes the appearance of having been filled with fragments of crushed killas, united by crystalline iron pyrites. When a lode of this description has been opened upon by levels or otherwise, the pyrites becomes rapidly oxidised, the veinstone is quickly disintegrated, and very heavy timbering is required to keep the ground open.

The ores raised at Devon Great Consols are usually of a low produce for copper, but they contain in addition a considerable amount of arsenic. A large proportion is consequently roasted previous to being sold as copper ore; this operation, in addition to yielding a valuable product in the form of white arsenic, materially increasing the percentage of copper in the residues. About six-sevenths of all the ores now sold are calcined for arsenic previous to being sent to market.

The principal workings of the mines do not extend to a depth much exceeding 220 fathoms below the adit, which is sixty fathoms from the surface; one shaft has, however, been sunk to a depth of 300 fathoms below the adit level, chiefly in the hope, which has hitherto been disappointed, of finding tin ore.

The workings comprise twenty-seven and a half miles of levels, six and a half miles of winzes and rises, and two and a half miles of vertical shafts. The largest return made in any one year was in 1857, when 28,836 tons of copper ore, of the value of £159,432, were raised and sent to market. The production of Devon Great Consols for 1881 was 10,922 tons of copper ore, of $4\frac{1}{16}$ produce, and of the value of £20,113. As before stated, the ores of these mines are usually arsenical, and during the year 1881, 2,851 tons of white arsenic, of the value of £23,324, were prepared by calcination.

The copper output remained at about the same figure, namely, 10,000 tons of ore, till 1885; in 1886, however, it was only 6,083, valued at £6,565; in 1890 it was 4,368 tons, worth £4,310, and has dropped in 1894 to 2,211 tons, valued at £2,907.

The mine has, however, maintained a steady output of between 2,000 and 4,000 tons of refined white arsenic, worth somewhere about £10 per ton. Thus the output for 1894 was 2,212 tons of arsenic, valued at £24,608.

Up to the end of 1894 Devon Great Consols has afforded 733,938 tons of copper ore, valued at £3,477,392. The value of its arsenic output, however, is even more than the above sum, exceeding four millions sterling; at present, as has been seen, the copper output is small compared with that of the arsenic, the latter being worth over eight times as much as the former.

Bedford United Mines, lying about a mile south of Devon Great Consols, have for many years been a fairly productive undertaking. During thirty years ending December 31, 1881, these mines yielded 47,544 tons of copper ore, of the aggregate value of £113,298. The production of the year 1881 was 656 tons of copper ore, of $5\frac{3}{4}$ produce, representing a value of £1,997.

Its output then improved a little, till in 1884 it produced 2,311 tons, valued at £6,964; like its neighbour, the Devon Great Consols, 1885 was, however, the last year in which it made anything like a fair return, and the yield having fallen in 1889 to 20 tons, the mine was closed down.

Huel Friendship, near Mary Tavy, which returned 110 tons of ore in 1811, was for many years a productive copper mine, but the yield of ore having become gradually reduced, the workings were ultimately suspended in 1857. The total yield of this mine during twenty-six years amounted to 32,250 tons of copper ore, of the value of £250,410.

Numerous lodes have at various times been opened in the neighbourhood of Bridestow and Okehampton, to the north of the Tavistock district skirting the southern flank of Dartmoor, but in no instance does a profitable mine appear to have been discovered.

In the Ashburton district, which includes all the area of clay slates skirting the eastern side of Dartmoor, and extending some miles north and south of Ashburton, are numerous lodes, some of which have yielded ores of copper and tin; they have, however, seldom yielded these ores in remunerative quantities.

Lead mining in Devonshire is of great antiquity, dating back to the time of the Roman occupation of the country. Some of the mines of this county were worked on account of the crown for the silver contained in the lead ore as early as the reign of Edward I., when they are recorded to have been profitable. The lead-mining districts of Devonshire are chiefly around Beer-Alston and Combe Martin. The mines of the latter district were re-opened in the reign of Elizabeth, and have been worked at various times since that period. Their working was strongly recommended to the Long Parliament in 1659, but they do not appear to have been again opened until the end of that century, and then without success. In 1813 they were re-opened and worked for four years, during which period they produced only 208 tons of lead ore. They were subsequently closed, and again worked in 1837. Of late years the most productive lead mines have been those in the neighbourhood of the Tamar, and the Exmouth and Frank Mills Mines on the banks of the river Teign, within ten miles of Exeter. One of the most productive of the Tamar mines was, some years since, flooded by the waters of that river breaking into the workings. A considerable amount of lead ore has also been raised at Christow.

The production of the lead mines of Devonshire has for many years been gradually declining, the total amount of lead ore produced in the county in 1881 being only ten tons. From 1851 to the end of 1863, a period of twelve years, the Tamar Silver Lead Mine yielded 7,910 tons of lead ore, containing 332,204 oz. of silver. The Frank Mills Mine from 1857 to the end of 1880, when the last sale of ore was made, a period of twenty-three years, produced 14,511 tons of lead ore, containing 247,151 oz. of silver.

A good deal of manganese is found in various parts of Devonshire. One of the most important deposits forms the filling of a fault in the Red Sandstone, and has been worked at Newton St. Cyres and other places in the neighbourhood of Exeter; Chillaton and Upton Pyne are also well-known localities. In 1825 the production of manganese was about 2,000 tons per annum; ten years later it had risen to 5,000 tons and continued to fluctuate between 500 and 5,000 tons till 1875, when about 3,000 tons were produced. The output then commenced to fall off; after having been very high during the seventies it came down between 1882 and 1886 to an average of 1,000 tons per annum, valued at about £2 per ton. In 1888 only 156 tons were produced, and though in 1892 the exceptional amount of 840 tons, valued at £1,050, was returned, in 1894 the production was only 31 tons, valued at £12.

Iron ore, principally red and brown hæmatite, has been produced for many years, but in very fluctuating quantities. Perhaps the best known locality is Combe Martin in North Devon, where a vein of hæmatite of good quality has been extensively worked. The production of iron ore in Devonshire rose gradually from some 1,500 tons in 1855 to 11,000 in 1864 and to 40,000 in 1866. It then fell to 7,000 tons in 1869, but reached 31,000 in 1873, from which figure it fell to 600 tons in 1879, though it rose to 12,600 in the following year. It then again fell rapidly to 1,000 tons in 1886, was 4,000 in 1890, and in 1894 was reduced to the insignificant total of 230 tons from Bovey Tracey.

Statistics relating to the production of Tin, Copper and Lead Ores, and of Arsenic in Devonshire.—For many years past nearly the whole of the tin produced in the United Kingdom has been obtained from the mines of Cornwall, Devonshire contributing a quite insignificant amount, although Devonshire is said to have formerly produced a larger amount of tin ore than Cornwall. The following table shows the production of this county for the last forty years, since separate statistics have been kept.

WEIGHT AND VALUE OF TIN ORE PRODUCED IN DEVONSHIRE FROM 1854 TO 1894.

Year.	Weight.	Value.	Year.	Weight.	Value.
	Tons.	£		Tons.	£
1854	300	—	1875	135	7,103
1855	180	10,874	1876	48	2,107
1856	136	9,660	1877	21	744
1857	95	7,331	1878	47	1,399
1858	55	3,173	1879	32	1,068
1859	111	7,945	1880	33	1,376
1860	175	13,951	1881	15	807
1861	238	18,086	1882	50	2,652
1862	203	13,668	1883	70	3,697
1863	282	18,940	1884	27	1,103
1864	308	19,685	1885	53	2,455
1865	256	14,554	1886	108	5,960
1866	184	9,313	1887	107	6,626
1867	78	4,137	1888	88	5,725
1868	54	3,086	1889	54	2,973
1869	128	9,381	1890	43	2,475
1870	45	3,394	1891	44	2,521
1871	139	10,558	1892	96	5,632
1872	143	12,647	1893	52	2,779
1873	94	7,277	1894	30	1,373
1874	1,082	10,356			

A comparison with the similar table on page 230 will show the relation that Devonshire bears to Cornwall as a tin producer; it must, however, be remembered that these are the totals only of such mines as clean their own tinstone. Any undressed ore is not included, but the amount of this is rarely important.

WEIGHT AND VALUE OF COPPER ORE OBTAINED FROM MINES IN DEVONSHIRE FROM 1856 TO 1894.

Year.	Ore.	Value.	Remarks.
	Tons.	£	
1856	42,024	215,644	
1857	37,800	222,416	
1858	36,332	194,133	
1859	36,415	188,737	
1860	35,283	186,081	
1861	35,796	187,188	
1862	40,095	196,012	
1863	40,742	189,208	Production of copper ore for ten years to end of 1871— Tons. 335,072 Value. £1,437,881
1864	37,978	194,197	
1865	38,156	184,776	
1866	34,471	151,481	
1867	31,163	143,898	
1868	30,640	128,748	
1869	32,723	86,056	
1870	24,752	84,096	
1871	24,352	79,409	
1872	23,630	88,668	
1873	14,810	48,200	Production of copper ore for ten years to end of 1881— Tons. 156,211 Value. £523,975
1874	12,826	52,746	
1875	14,097	86,398	
1876	16,276	58,240	
1877	16,980	50,484	
1878	12,648	26,575	
1879	12,736	30,616	
1880	15,076	42,539	
1881	17,132	39,509	
1882	19,201	66,133	
1883	18,198	41,797	
1884	18,081	36,412	Production of copper ore for ten years to end of 1891— Tons. 105,425 Value. £232,282
1885	15,013	25,241	
1886	10,076	15,992	
1887	5,184	8,800	
1888	6,936	16,558	
1889	2,659	5,547	
1890	6,038	9,197	
1891	4,039	6,605	
1892	2,823	4,264	
1893	2,471	5,940	
1894	2,314	3,012	

It will be noticed firstly that there has been a very rapid falling off in the output of copper since about 1886, and secondly that

Devon Great Consols plays a very important part in the mineral production of the entire county.

The subjoined table gives the production of lead ore in Devonshire for forty years, and shows the gradual falling off which has taken place in the yield of the lead mines of this county; no lead has been produced by it since 1890.

WEIGHT OF LEAD ORES OBTAINED FROM THE MINES OF DEVONSHIRE FROM 1852 TO 1891, WITH THE AMOUNTS OF LEAD AND SILVER RESPECTIVELY CONTAINED IN THEM.

Year.	Lead ore.	Lead.	Silver.
	Tons.	Tons.	Oz.
1852	2,977	1,917	91,340
1853	3,014	1,798	106,236
1854	4,139	2,612	119,288
1855	4,035	2,292	89,908
1856	3,138	2,000	77,456
1857	2,590	1,535	50,262
1858	2,779	1,695	53,366
1859	3,172	2,090	66,875
1860	3,018	2,030	53,059
1861	2,762	1,791	45,187
1862	2,079	1,376	39,265
1863	1,578	1,080	20,357
1864	1,656	1,093	21,480
1865	1,847	1,147	33,865
1866	723	471	13,017
1867	803	526	13,719
1868	1,522	1,141	39,865
1869	1,080	677	27,451
1870	1,235	829	24,706
1871	940	657	13,805
1872	746	522	10,392
1873	676	472	6,510
1874	451	311	7,809
1875	335	242	4,542
1876	437	327	5,890
1877	337	252	4,948
1878	234	169	3,286
1879	129	97	1,915
1880	31	23	226
1881	10	8	60
1882	13	9	65
1883	—	—	—
1884	2	1	2
1885	3	1	2
1886	20	7	2
1887	—	—	—
1888	—	—	—
1889	—	—	—
1890	182	140	2
1891	—	—	—

Production for ten years to end of 1861—

Lead ore.	Lead.	Silver.
Tons.	Tons.	Oz.
31,624	19,760	752,977

Production for ten years to end of 1871—

Lead ore.	Lead.	Silver.
Tons.	Tons.	Oz.
13,463	8,997	247,530

Production for ten years to end of 1881—

Lead ore.	Lead.	Silver.
Tons.	Tons,	Oz.
3,386	2,423	45,578

Production for ten years to end of 1891—

Lead Ore.	Lead.	Value.
Tons.	Tons.	£
220	158	1,318

It is worth noting that whilst the percentage of lead in the ore has remained approximately constant during this period, its richness in silver has very markedly decreased.

As in the case of Cornwall, the production of white arsenic forms an important factor in the mineral wealth of Devonshire; as already pointed out, Devon Great Consols is now the chief contributor to this output, which precisely as in Cornwall reached its apogee in 1884 and 1885, and has been slowly but irregularly declining since then as shown by the subjoined table:—

Production of Arsenic in Devonshire from the Year 1884 to 1894.

Year.	White Arsenic.		Arsenical Pyrites.	
	Weight.	Value.	Weight.	Value.
	Tons.	£	Tons.	£
1884	5,395	34,922	—[1]	—[1]
1885	6,006	30,931	—[1]	—[1]
1886	3,236	23,131	2,504	1,851
1887	2,957	22,336	4,262	3,108
1888	3,040	25,092	3,882	3,086
1889	2,831	26,150	5,245	4,864
1890	4,133	34,224	3,578	2,733
1891	3,001	32,170	3,991	3,136
1892	2,547	24,086	3,411	3,921
1893	4,225	44,223	2,201	2,309
1894	2,901	32,212	1,769	2,480

Somersetshire.—Lead and zinc ores were formerly obtained from the Carboniferous limestones of Somersetshire, but at the present time no mines for these metals are being worked in that county. A small quantity of lead was, however, still annually obtained in the Mendip Hills as recently as 1884 from the treatment of ancient slags and slimes, some of which are believed to be residues resulting from Roman workings.

Many important mines of spathose iron ore have been opened in the Brendon Hills in this county, and have been worked since the year 1852 by the Ebbw Vale Iron Company, who employed the ores obtained from them for the manufacture of spiegeleisen. Although this ore is of common occurrence in many parts of the Continent, it is in this country only found in considerable quantities in the following localities, namely, in Weardale in Durham, where, associated with lead and zinc ores, it forms veins in the Carboniferous limestone, at Perran in Cornwall, at Exmoor in Devon, and in the Brendon Hills in Somersetshire, where it forms a chain of irregular lodes, coursing about N. 55° W.—S. 55° E., and dipping at varying degrees but averaging about 45° to the S.W., in slaty

[1] Included in the totals of white arsenic.

rocks of Middle Devonian age. The system of veins extends over a distance somewhat exceeding five miles, and their maximum aggregate thickness is about twenty-seven feet. The ore usually contains from 13 to 14 per cent. of protoxide of manganese, and yields spiegeleisen of good quality, containing about 20 per cent. of manganese.

The range known as the Brendon Hills runs nearly E. and W., and is about six miles south of that portion of the Bristol Channel lying between Watchet and Minehead. On their northern side they rise somewhat abruptly, but in the opposite direction their slope is much more gradual. At their highest point they reach an elevation of 1,350 feet above the sea-level, and the slates, which near the surface are grey in colour, acquire a bluish-green tint in depth, and usually dip towards the south-east. At Treborough, two miles north of the highest point of the range, these slates have been extensively quarried for roofing purposes. Attention was, in modern times, first directed to this locality by evidences of extensive ancient workings, with regard to the age of some of which there is no conclusive evidence; a coin of Domitian was, however, found in one of the old workings at Kennesome Hill, and Roman coins have been found in the vicinity of the old workings in the Brendon range. A wooden shovel and a turf dam were also found, in 1865, at the bottom of one of the ancient workings at a depth of 100 feet below the surface; this dam was apparently the last of a series extending from the top to the bottom, and by means of which the water was removed by dipping from one to another.[1]

In addition to iron ores, the lodes contain quartz, and occasionally fragments of the country rock. The quartz, which most frequently occupies the north side of the lodes, is not much intermixed with the ores, but more frequently assumes the form of distinct lenticular masses. Near the surface the carbonate of iron has everywhere been converted into brown hæmatite by the action of water and atmospheric air. The annual production of these mines amounted to about 27,500 tons in 1880, after having exceeded 40,000 tons from 1873 to 1878, but since 1882, in which year 36,000 tons were produced, the production of Somersetshire ore fell off most rapidly; in 1883 it was only 4,400 tons and is now practically *nil.*

THE FOREST OF DEAN.—The district known as the "Forest of Dean" is situated within that part of Gloucestershire which is

[1] Morgan Morgans, "The Brendon Hills Spathose Iron Ores and Mines," *Proceedings of South Wales Institute of Engineers*, vi. p. 78.

bounded by the rivers Severn and Wye. This was probably one of the first seats of the iron trade in Great Britain, and its history is consequently of exceptional interest. In the reign of Henry the Second, the Forest comprised the whole of the land lying within the above boundaries, but by successive reductions it has now become curtailed to the central district, occupying the area lying between Little Dean and Christ Church on the east and west, and Eccleswall and Bream on the north and south.

The strata of this district assume the form of a basin of which the greatest depression is near the centre; its longer axis extends for about eleven miles from N. to S., while the transverse axis in its widest part ranges about seven miles from E. to W. The central portion of this area consists of coal-measures, which are surrounded by a belt of Carboniferous limestone, which is itself bordered by Old Red Sandstone.

That the Romans carried on the manufacture of iron on a large scale, and for a lengthened period, in the Forest of Dean is sufficiently proved by coins and other relics of that people, which have been found under heaps of slags, which were once so abundant as to form an important proportion of the material supplied to the local iron furnaces. The earliest historical records respecting this district are clearly identified with its iron trade; for although the pages of the Domesday Book supply no definite information relative to this industry, they nevertheless distinctly allude to the production of iron in the immediate neighbourhood. It is there stated that the bolts and bars required by the ship-builders of the Royal Navy were obtained from the city of Gloucester, and there can be little doubt that the iron was produced in the Forest of Dean. In the year 1140 the Abbey of Flaxley was founded by Roger, eldest son of the Earl of Hereford, by whom it was partially endowed, and by whom it was named the "Abbey of St. Mary de Dene," its site being at that time included within the precincts of the Forest. The institution of the abbey was confirmed by Henry II., who further enriched it by granting to the monks permission to feed their cattle and hogs in the Forest, to repair their buildings with its timber, and to establish iron forges within its boundaries. For a period of more than five centuries the iron trade established by the monks of Flaxley appears to have been carried on in almost any part of the Forest capable of furnishing the requisite ore and charcoal, and where a running stream supplied the power necessary for a blast.

The mineral district of the Forest of Dean is remarkable for the regularity of its strata, since each bed exhibits a continuous line of outcrop around the whole edge of the basin, with a uniformity without example in any other locality in this country. The coal-measures are naturally divided into three series, of which the middle affords the greater portion of the large supply of coal now furnished by the district. The strata between the upper and middle series consist almost exclusively of argillaceous shales, with, here and there, thin beds of sandstone. Below the middle coal-seams the measures undergo a decided change, and instead of the shales before referred to, a hard sandstone prevails, and continues, with but little variation, down to the Coleford High Delf seam, which is one of the lowest belonging to the lower coal series.

The Farewell Rock or Millstone Grit, which underlies the coal-measures throughout the Forest of Dean, contains, in its lowest bed, a deposit of iron ore which, to a small extent, is worked on its eastern outcrop ; but the extensive deposits of ore, which from the earliest times have supplied the iron of Dean Forest, occur in large pockets or *churns* in the upper beds of the Carboniferous limestone. The most productive of these beds is a crystalline limestone locally called *crys, crease*, or *mine measures*. Such churns often contain several thousand tons of brown hæmatite, which is for the most part soft and easily worked, but which, nevertheless, varies considerably in quality. One of the largest churns measured 350 yards long, 12 to 14 yards high, and the same in breadth, whilst several have yielded up to 60,000 tons of ore.[1]

The Black Brush ore sometimes contains as much as 90 per cent. of peroxide of iron, but the poorer varieties (known as gray ore), being contaminated by an admixture of clay and carbonate of lime, are proportionately less rich in iron. The most important workings in the limestone of this district are those situated on its eastern outcrop, where cavities in the almost perpendicular beds are filled with deposits of rich ores in enormous quantities. On the western side of the field, where the strata are less inclined than those on the other side, iron mining has long been extensively carried on. All the most successful mines, however, are found to lie to the dip of the excavations made by the ancient miners, who had frequently penetrated to greater depths than could have been expected when we consider the means at their disposal.

In accordance with the general practice among ancient craftsmen, the miners of Dean Forest were associated in a guild or trade

[1] J. D. Kendall, *The Iron Ores of Great Britain*, p. 130.

corporation, and their prescriptive rights and privileges were guarded with extreme jealousy and care. For admission into this guild it was necessary that a man should have been born in the hundred of St. Briavels, and should have worked for a year and a day in either a coal or iron mine; he was then entitled to be admitted a Free Miner of the Forest of Dean.

The original laws of the Order of Free Miners as to modes of working and the extent of area allowed to each workman, were only applicable to very shallow workings. Consequently, in proportion as the demand for ore and coal increased and more expensive appliances for obtaining them from greater depths became necessary, the rules of the ancient code had, from time to time, to be relaxed in such a way as to afford opportunities for more extensive workings and the employment of larger capitals. This, however, resulted in endless disputes, until, under the Dean Forest Mining Act, commissioners were appointed to assign boundaries to the various mineral tracts, and to arrange the difficulties which the old Forest laws had been found inadequate to meet. The various collieries and iron mines of this district are now held under awards of these commissioners made in the year 1841. The decade from 1862 to 1872 seems to have been the period in which the iron trade of the Forest of Dean was at its best, with an annual ouput of some 150,000 tons. The annual production of iron ore was approximately 79,000 tons in 1882, but it has been steadily decreasing till in 1894 it was only 27,750 tons, valued at £10,000; of this amount the Crown lands produced 17,750 tons.[1]

Iron Ores of the Carboniferous Limestone—Northern Counties.—The principal mass of the iron-producing Carboniferous limestone of the northern and north midland counties of England emerges from beneath the coal-measures of the counties of Durham and Northumberland in the east, and is bounded by a steep ridge overlooking the Vale of Eden on the west. It reaches its highest point in the mountainous range of Cross Fell, and forms a tract of moorland country which, in the neighbourhood of Alston, extends for a width of twenty-five miles, while in the elevated region adjoining the Scottish border it stretches almost completely across the island.[2] After an interval of a few miles the same formation

[1] For information relative to this district consult *The Forest of Dean*, by Rev. G. H. Nicholls, 1858; also Arnold Thomas, "The Forest of Dean," *Proceedings S. Wales Inst. of Engineers*, vi. 1870, p. 200.

[2] W. W. Smyth, "The Iron Ores of Great Britain," *Memoirs of the Geological Survey*, 1856, part i. p. 15.

again rises towards the west, from beneath the New Red Sandstone of Penrith, and the coal-measures of Workington and Whitehaven, and forms a comparatively narrow belt around the older slaty rocks of the Lake district. The structure of the high land, on which are situated the towns of Alston, Hexham, and Haltwhistle, differs materially from that of the contemporaneous formations occurring, both in England and Wales, further south, which, for a great thickness, consist principally of almost uninterrupted beds of limestone. In the north, on the contrary, the actual limestone plays a comparatively subordinate part, and alternates with strata of sandstone and shale, locally known as *hazle* and *plate*. In some of these bands of shale are found nodules of clay ironstone, of which the aggregation and mode of occurrence exactly resemble those of similar ores in the coal-measures.

The majority of the mineral veins of the vicinity of Alston, which produce the lead ore for which that district is celebrated, range nearly east and west, and intersect the whole of the strata belonging to the Carboniferous limestone; they are, however, much more productive in certain of the beds than in others. Some of these lead veins in portions of their course, instead of being composed of the usual veinstones accompanying lead ore, such as calcite, fluor spar, &c., are filled with brown iron ore. The rich lode of Rodderup Fell, known as the Craig Green or Bracken Syke Vein, in the "Scar Limestone," belongs to this class, and varies from sixteen to twenty feet in width. Certain of the lodes in the vicinity of Alston, producing ore of this kind, have been extensively wrought. Among others the Manor House Vein, near the railway station, has yielded large quantities of brown iron ore of good quality. This vein is about twelve feet in width, and its productiveness is increased by the occurrence of flats, which, at distances of a few feet apart, penetrate between the bedding of the limestone which constitutes the country rock. Fig. 71 is a diagrammatic sketch, given by Smyth, representing a section of this lode. On the northern shoulder of Cross Fell, and in Weardale, outcrops of similar iron veins occasionally present themselves.

In the eastern part of this region spathose iron ores make their appearance abundantly in the lead veins, and form the veinstone accompanying galena, for which the mines are principally wrought. At the mines of Allenheads spathose ore occurs both in regular veins and in flats, while at Stanhope Burn the veins are so charged with this mineral that at a spot where several of them occur in close proximity to one another, and which is further enriched by the interlacing of numerous strings, the whole surface has been removed by the Weardale Iron Company, and the rock taken away by quarrying, a considerable amount of lead ore being separated during the operation. In many places in this district brown peroxide of iron is frequently mingled, especially near the surface, with spathose ore, from which it has doubtless been derived. These mines are now being steadily worked, since their value has been recognised. A good deal of ore, locally known as *rider*, had been left standing when the lodes were worked for lead exclusively, but has since been got. Weardale iron ore is either spathic ore, which occurs in a white or yellowish-gray crystalline form, called *white ore* by the miners, and as a dark gray, almost black, microcrystalline mass, feebly magnetic, called locally *steel-*

FIG. 71.—Section of Manor House Lode.

gray ore, or else brown hæmatite, which is obviously a product of the decomposition of the former, most likely *in situ* to a great extent, by meteoric agencies. Masses of white ore are often found embedded in the brown ore, passing gradually into it. These ore deposits are chiefly developed in the Great Limestone, and in places where this is traversed by two series of fissures crossing each other, extensive *flats* of ore are often developed, as for instance at Carrick Mines, where a series of flats of great extent and some eighteen feet in height follow the course of a narrow vein about eighteen inches wide, running nearly east and west, filled with white and brown ore, and occasionally carrying stones of galena. In the hazle beneath, this vein is reduced to a thread only two inches wide. The ore of the flats passes gradually into the limestone walls, and there is little doubt that it has been formed by metasomatic action on the latter rock. In this connection it is worth noting that, wherever the limestone strata of the district are traversed by metalliferous veins, not only is spathic ore a universal ingredient of the gangue, but it has also been found that the limestone forming the walls of the vein contains a considerably higher percentage of iron than does the same stratum of rock at a distance from such veins. The Weardale Company raised in 1894 2,680 tons of iron ore yielding 30 per cent. of metal and valued at £1,000.

The red hæmatite from the vicinity of Whitehaven in Cumberland, and of Furness in Lancashire, is a very valuable ore, not only on account of its high tenor of iron, usually 50 per cent. or more, but also because of the very low proportion of phosphorus which it contains, so that it is admirably adapted for the production of pig iron for steel-making. This ore is obtained either from Carboniferous rocks or from those of Silurian age; practically, however, it is almost entirely derived from the former, since the deposits in the Silurian rocks are of extremely limited extent. The Carboniferous limestone series, in which the principal deposits occur in both districts, consists mainly, as before stated, of alternations of limestones with shales and sandstones.

The sandstones and shales are generally very thin, often not more than two or three feet, and seldom exceeding twelve feet, in thickness. On the other hand, the limestone occurs in enormous beds, sometimes exceeding 300 feet in thickness, and it is in these thick masses of Mountain Limestone that the hæmatite is principally found. The ore fills fissures and lake-like basins in this rock sometimes immediately below the drift, while at others it presents itself in an irregular form deep down in the Carboniferous limestone. It is found in almost every bed, from the lowest, resting on the Silurian, to the highest, forming the base of the Grits and Yoredale rocks, at Whitehaven and Furness respectively. It is evident, therefore, that there is a wide difference in the geological horizon of the various deposits. In consequence, however, of the inclination of the limestone and the extent to which it has been denuded, this difference of geological horizon does not always affect the actual level of the deposits, and many of them occurring in the lower beds are found much nearer the surface than those in the higher ones.

At Whitehaven, some of the finest deposits of iron ore occur in the upper beds of limestone, that is, in those lying immediately below the Grits. At Bigrigg, Crowgarth, and Parkside, the ore is found in large, irregular masses in the limestone immediately under the Millstone Grit, one of the beds of which forms in each case the roof of the deposit. In section these deposits present in many respects the appearance of a bed, since they follow the dip of the rocks in which they lie, and usually preserve a tolerably uniform thickness, which in different deposits varies from four to above forty feet. The roof of sandstone, and the floor of limestone are, in some cases, parallel for very considerable distances; at Parkside, for instance, the roof and floor remain parallel for a distance of nearly 200 yards. Fig. 72, from a sketch by Mr. J. D. Kendall, represents a vertical section of that deposit taken along its line of dip.[1]

This affords a striking example of the way in which such deposits sometimes vary in thickness. To the left of *a* the depth

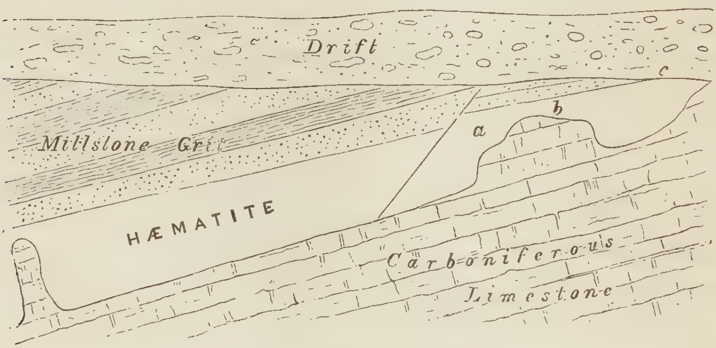


FIG. 72.—Parkside iron ore deposit.

of the ore is not less than sixty-five feet, while at *b*, only a short distance from it, it does not exceed four feet. These variations in thickness are always due to irregularities in the limestone floor, as the roof invariably forms a regular even plane having the same general dip as the strata surrounding the ore. These variations in thickness usually take place in the direction of the strike of the strata. But few of the deposits occurring immediately under the Grits are found to be at any great distance from the upper edge of those rocks, and in many cases the ore comes from beneath them up to the bottom of the drift, as shown at *c*. Since, however, the inclination is somewhat great, the deposit, as it extends towards the dip, rapidly becomes covered by a considerable thickness of rock. The superficial extent of these deposits is sometimes very large, that at Parkside having an area of eighteen acres, while numerous others vary in size from two to ten acres.

[1] "The Hæmatite Deposits of Whitehaven and Furness," *Trans. Manchester Geol. Soc.*, xiii. 1876, p. 231.

In Furness one deposit only has, as yet, been discovered in the highest bed of limestone lying immediately beneath the Yoredale rocks. This deposit is at Stank, and was discovered in searching for coal.

The deposits in the intermediate beds are many and various. Some of them, and especially those in Furness, lie immediately below the drift in basins hollowed in the limestone similar to those which occur in the lower beds. Others, and particularly at Whitehaven, are at considerable depths in the limestone enclosed in irregular caverns, which are sometimes at a depth of 35 fathoms from the surface, and are surrounded by limestone on all sides. A good example of a lake-like deposit is seen, Fig. 73, at the open cutting of the Crossfield Iron Company. In Furness there are a

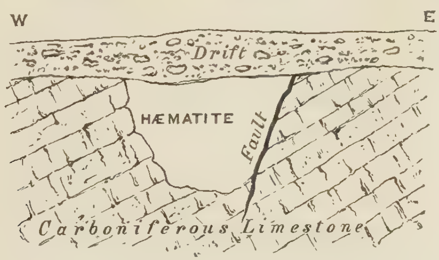


FIG. 73.—Open works; Crossfield Iron Company.

great number of shallow basin-like deposits, all those in that district, with but few exceptions, belonging to this class.

The deposits in the lower beds of limestone resting upon the Silurian rocks are among the finest which have been found in the Furness district. Amongst these may be mentioned those of Park and Lindal Moor, the first of which extends over an area of fifteen acres, and at one point has been proved to a depth exceeding 300 feet. The deposit of Lindal Moor is 900 yards in length and about twenty-three yards wide. One or two very fine deposits of hæmatite occur in the lower limestone beds at Whitehaven, such as those at Todholes and Woodend. The lower deposits usually occur in dishes or hollows in the limestone immediately below the drift, and in close proximity to rocks of Silurian age. Sometimes they even rest upon Carboniferous limestone on one side and upon Silurian rocks on the other, as shown in Fig. 74. Both the Park and Lindal Moor deposits rest partly on Silurian rocks, as do also those of Todholes and Woodend. At Martin, in Furness, there is a deposit of this class which, on account of the peculiar circumstances under which it occurs, is worked as an open quarry. When first discovered the ore was covered by about thirty feet of drift, which has since been removed, thus affording an opportunity of thoroughly examining its form and character. It lies on the limestone, by which on all sides, except one, it is surrounded. Where the limestone is absent the ore rests upon the underlying slate, which rises at a high angle from below that rock. The length of this deposit is about 260 feet, and its width 200 feet, while the greatest depth to which it has yet been proved is somewhat over fifty feet.

Wherever these deposits occur, whether just below the Grit, in the middle of the series, or down upon the Silurian slates, their

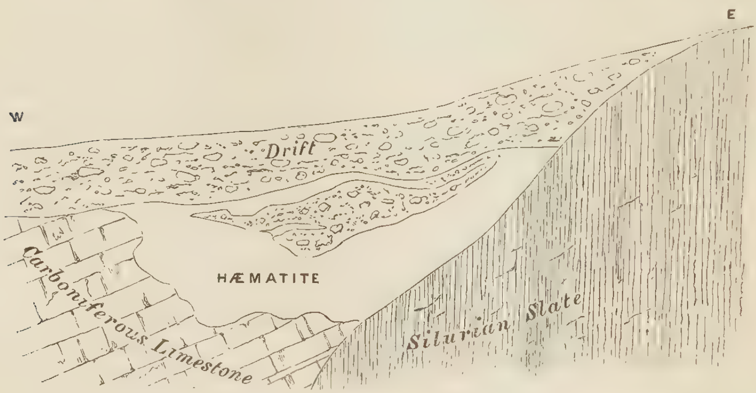


FIG. 74.—Iron ore deposit on Carboniferous limestone and Silurian slate.

longer axis almost invariably coincides with the direction of the principal joints of the limestone rock.

At Whitehaven the hæmatite is usually of a dull red colour, and occurs in hard compact masses containing numerous irregular cavities, which are frequently lined with a botryoidal concretion generally known as *kidney ore*, on which a coating of specular iron ore, quartz, and calcite is sometimes formed. In Furness the ore, with the exception of that worked at Lindal Moor, Stank, and Askam, differs materially from that at Whitehaven. Instead of the hard solid masses met with in that district, the Furness ore consists, to a large extent, of loose incoherent material composed of delicate filmy scales of micaceous iron, soiling the fingers when touched, and enclosing fragments of more compact ore, many of which have a concretionary structure. The harder hæmatite, locally known as *blast ore*, is entirely employed for smelting purposes, while the softer variety, sometimes known as *smitty ore*, is much used for the purpose of forming the bottoms of puddling furnaces.

Some of the harder ores of the Furness district exhibit very distinct lamination, and concretionary nodules of hæmatite are met with which, on being broken, are found to contain a nucleus of limestone. No fossils have ever been found in the soft crystalline ore of Furness, but large numbers, all belonging to the Mountain Limestone series, occur in the more solid ores of Lindal Moor. It would appear probable that the hæmatite which now fills the basins and hollows of the Carboniferous Limestone was originally deposited in the form of carbonate of iron. It will be easy to conceive that, on a solution of this substance in water containing carbonic acid coming in contact with limestone, the carbonate of iron would be deposited, and its place in the solution occupied by carbonate of lime. When the carbonate of iron had been thus formed, its change into hæmatite was probably effected by a process somewhat analogous to that by which siderite is so often seen to become converted into brown iron ore. That a portion at least of the hæmatite has replaced carbonate of lime becomes evident from the fact that numerous fossils of the Carboniferous limestone have been found in the ore, and that some of them have only been partially converted into oxide of iron (*see also* p. 176).

It is somewhat difficult to conceive whence the iron forming such numerous ferruginous deposits could have been derived, but Mr. Kendall suggests the coal-measures as the probable source from which this metal originally came. He further remarks that it is well known that the sandstones and shales belonging to this formation contain a large percentage of iron; and as these rocks at one time probably overlaid the Carboniferous limestones of the hæmatite-producing districts, he thinks it not improbable that a large proportion of the iron in the limestones may be the result of the percolation of waters, charged with carbonic acid gas, through superincumbent beds which have been since removed by denudation.

In 1881, the production of red hæmatite in Cumberland was 1,615,635 tons, while that of Lancashire amounted to 1,189,836 tons. The largest year's work in Cumberland was in 1882, when 1,725,478 tons were produced. The production has declined slowly and irregularly since that time, and amounted in 1894 to 1,286,590 tons from Cumberland, estimated to yield 54 per cent. of metallic iron, and valued at £698,457, whilst in Lancashire the output was 870,500 tons, estimated to yield 51 per cent. of metal, and valued at £372,576. The Furness district, like Cumberland, seems to have been at its highest point of productiveness in 1882, when it produced 1,408,693 tons; it decreased steadily and fell below the million in 1890, and seems still to be slowly falling.

Ironstones of the Coal-measures.—The clay ironstones of the coal-measures, which have so largely contributed to the prosperity of the iron trade of this country, often form layers of more or less regular nodules enclosed in beds of shale and clay belonging to that formation. They occasionally coalesce into beds, which are seldom of any considerable extent or thickness. These nodules consist essentially of carbonate of iron, associated with varying proportions of the carbonates of lime and magnesia, together with a certain amount of argillaceous matter; they also usually contain a little carbonate of manganese. Such nodules are often concretionary, and contain fresh-water shells, remains of fish, fragments of plants, and other fossils. The concretions are sometimes of such small size that they have received the name of *pins*, *pennystones*, and other similar appellations; occasionally they are large spheroidal masses exceeding a foot in diameter. The larger nodules are frequently divided by irregular cracks, which are usually filled by such minerals as calcite, quartz, iron pyrites, chalcopyrite, blende, and galena. Millerite or sulphide of nickel and mineral tallow occur together in the nodules of clay ironstone of Glamorganshire. When recently broken, nodules of ironstone commonly exhibit a light gray or bluish tint, which on exposure to the atmosphere rapidly becomes brown through oxidation.

Ores of this character almost invariably contain phosphoric acid, of which the proportion occasionally exceeds one per cent. Clay ironstone sometimes exhibits the regular structure known as *cone in cone*, in which case the seam has a tendency to divide into cones, the bases of which are towards the top and bottom of the bed, while their apices are directed towards the centre. The English coal-fields most plentifully supplied with ores of this class are those of Staffordshire, Shropshire, Yorkshire, and Derbyshire; while but little is found either in Northumberland, Durham, or Lancashire. Clay ironstones are worked both in North and South Wales and in Scotland. They are sometimes brought to the surface through the pit employed for extracting the coal, but at others they are obtained by entirely independent workings. To give the names only of all the numerous localities which have in this country furnished clay ironstone from the coal-measures would occupy more space than can be devoted to the subject; but a brief notice of one or two of the more productive localities may, nevertheless, not be out of place.

In the northern district of Yorkshire, the lower series of the coal-measures is developed to an extent not observable in the south by the occurrence of beds of coal and ironstone which have given rise to the establishments of Low Moor, Brierley, Bowling, &c., celebrated for the production of the best iron made anywhere in Great Britain. Coal-measure ironstones are alone employed in this district, and are principally derived from two groups of strata, known respectively as the White-Bed Mine and the Black-Bed Mine; a third, called the Brown Rake, was also formerly worked. The ores are not without phosphorus, and neither their abundance nor their quality can have materially contributed to the celebrity of the iron produced. This superiority appears due rather to the care bestowed on every stage of its manufacture, and to the great purity of the fuel employed, than to any excellence of the ore treated. The coal used is obtained from the seam called the "Better-bed," which lies beneath the ironstone, and attains a thickness varying from one foot eight inches to two feet; it differs from ordinary coal in its remarkable freedom from pyrites, and is exclusively made use of for the processes of refining, puddling, &c.

An average section of the measures in this district is given in the following table.[1]

WHITE-BED IRONSTONE, BRIERLEY.	Top flats. Low flats. White balls. Middle balls. Low measures.
BLACK-BED IRONSTONE, LOW MOOR. In 18 beds.	Top balls. Flat stone. Middle balls. Rough measure. Low measure. Basset stone.

	ft.	in.		ft.	in.
Royd's or Black-bed coal	1	4	to	2	3
Various measures—					
Roof of coal, black shale, with numerous fish remains, and small white nodules of ironstone				120	0
"Better-bed" coal	1	4	to	2	0
"Floor" of indurated clay, with small scales of white mica.					
Various measures				150	0
Flagstone exported for London pavement.					

The upper or White Bed is characterised by the pale drab colour of the majority of its courses, even when they occur in

[1] "Iron Ores of Great Britain," *Memoirs of the Geological Survey*, 1856, part i. p. 32.

bands of dark shale. The Black Bed exhibits the ordinary blackish-gray tint of clay ironstone, and occurs in detached nodules of varying dimensions.

In South Yorkshire, extending from Parkgate near Rotherham to Tankersley, and onward to the west of Barnsley, numerous outcrops of important beds of ironstone may be traced. Whenever these beds came to within a short distance of the surface they were actively worked by means of *bell pits*, which are small, shallow shafts numerously distributed at regular intervals along the strike of the beds. This system of working, in conjunction with its frequently accompanying open cuttings, often imparts a strange aspect to the country. The pits and irregular openings thus extending over considerable areas, render them totally unfit for cultivation, and these old workings having been planted, the line of outcrop of the ironstone is often distinctly indicated by the belts of trees.

The more important of the ironstone beds worked in the West Riding are comprehended within a thickness of about 1,000 feet of measures extending between the Barnsley Thick Coal and the Silkstone; they are known as the Swallow Wood, Lidgate, Tankersley, Thorncliffe Black Mine,[1] Thorncliffe White Mine, and Clay Wood Mine.

The Derbyshire coal-field being the extension, southward, of that of Yorkshire, many of the same seams may be traced continuously over a large area. The ironstone beds, however, usually possess less persistency of character than the coal-seams, and comparatively few of them continue to be productive throughout the whole length of the county. On the contrary, many of the seams of nodular ironstone, locally called "rakes," which in certain districts are extensively worked, are found, within a comparatively short distance, either to thin out, or to so deteriorate in quality as to be unworkable.

The total thickness of the Derbyshire coal-measures may be taken at about 2,000 feet, including the very productive seams of the Pender Park, Staveley, and the Cement Rake and Brown Rake of Alfreton and Butterley. The Dog-tooth Rake of Chesterfield, 24 feet in thickness, is one of the most important in this field, and is remarkable from the fact that one or more of its beds are almost entirely composed of fossilised shells of *Anthracosia*. This shell, probably of several species, is found in great abundance in all the upper beds of ironstone. In some of the lower measures, it is

[1] In the iron districts the word *mine* is often used as synonymous with *ore*.

either less numerous or is altogether wanting; among the very lowest, however, it again appears.

With regard to the prolongation of these beds southward, much confusion has arisen from the same name having been given to distinctly different beds, yielding ores of a somewhat similar character. The Three-quarter Balls form a very productive seam below the Furnace Coal at Clay Cross. Many of the lower ironstones contain, in addition to bivalve shells, the remains of various coal plants, which frequently form the surface of a nodule, and have become completely converted into iron ore. The balls of ironstone in this neighbourhood are often pierced by small tubular hollows left by rootlets of stigmaria, which are sometimes filled with blende. The most remarkable of all the ironstones of the district is the Black Shale Rake, which is nowhere so well exposed as at Hady, near Chesterfield, where it has been long extensively worked for the use of the blast furnaces at Staveley. At this place it consists of two distinct bands of gray shale respectively 15 and 21 feet in thickness, loaded with numerous rows of ironstone nodules, and separated from one another by 12 feet of unproductive shale. Among the ironstones of this deposit, the "cheeses" are remarkable for the symmetrical cracks caused by contraction; these are mostly filled with carbonate of lime, containing iron and magnesia, but open cavities lined with crystals of blende are of frequent occurrence. The "Old Man" and "Old Woman" are compact gray ironstones with a somewhat conchoidal fracture which exhibit numerous cracks, and these, in addition to impure carbonate of lime, contain well-defined crystals of blende and galena. Copper pyrites and iron pyrites sometimes occur in the same way, and not unfrequently occupy the hollows left around the casts of fossil shells. The upper measures of the Dale Moor Rake, the lowest known in the Derbyshire coal-field, yield an ironstone of a light drab colour, which is remarkable for the number of plant remains, particularly rootlets of stigmaria, which it encloses. The "Bottom Balls" are especially remarkable for containing a large number of entire fishes, usually from four to seven inches in length, belonging to the genera *Palæoniscus* and *Platysomus.* The large number of courses in these lower ironstone measures, together with the great thickness of the shales in which they occur, renders it necessary to work them by open cuttings on a very large scale.

The yield of ironstone per acre must necessarily depend on the thickness of the nodules in the measures and the closeness and regularity of their distribution. The Tankersley Mine, in Yorkshire, a bed of shale about six feet in thickness, contains from twelve to fifteen inches of ironstone, and yields, on an average, 2,000 tons per acre. At Parkgate the Old Black Mine, 11 inches thick, yields 1,500 tons per acre, while the Clay Wood Mine, only five and a half inches in thickness, produces from 1,500 to 1,600 tons per acre. In Derbyshire, at Butterley, the Brown Rake, consisting of three thin measures of ironstone in a band of shale, of the total thickness of four feet six inches, yields 2,500 tons per acre.

The Chesterfield Black Shale Rake, which is the most productive in the district, consists of twenty bands of ironstone nodules varying from half an inch to two and a half inches in thickness, interspersed through about thirty-seven feet of shale. The total thickness of ironstone is about twenty-eight inches, and this affords a yield varying from 4,000 to 7,000 tons per acre.

The annual production of coal-measure ironstones in Yorkshire and Derbyshire was, respectively, about 330,000 and 60,000 tons in 1881. The largest quantity of ironstone of this class raised in any one county is, however, obtained from Staffordshire, where the production in that year somewhat exceeded 1,700,000 tons. There has been a continual falling off in the output of these coal-measure ores for many years; in 1894, Yorkshire (east and west) produced 67,191 tons, Derbyshire 8,481, and Staffordshire 846,515 tons. In North Staffordshire blackband ironstone occurs in beds varying from four to nine feet in thickness.

Iron Ores of Mesozoic Age.—It has been pointed out by Kendall (*loc. cit.*) that whereas thirty years ago the bulk of British ores was derived from Palæozoic rocks and only some 10 per cent. from the Mesozoic, the latter rocks now produce from 50 to 60 per cent. of the output, and he illustrates this change by the following table:—

Ores raised in the United Kingdom.

	In 1855. Tons.	In 1890. Tons.
From the Mesozoic rocks	1,044,384	9,060,169
From the Carboniferous formation—		
Carbonates from the Coal-measures	7,848,635	2,414,017
Hæmatite from the Mountain Limestone	630,225	2,424,960
From other rocks	30,497	54,792
	9,553,741	13,953,938

It is clear from these figures that there has been a large actual decrease in output of the carbonates from the coal-measures, whilst there has been an important increase in the production from the

Mesozoic rocks, due in large measure to the development of the Cleveland district. The marlstone bed forming the highest portion of the Middle Lias series is often ferruginous, and in certain localities constitutes a valuable ironstone; it sometimes attains a thickness of over twenty feet. In many respects the ore resembles that from the Northampton sands, excepting that, instead of being siliceous, it is somewhat calcareous. This ore has been worked at Adderbury, Steeple Aston, and Fawler near Stonesfield, Oxfordshire.

Brown hæmatites of a somewhat sandy and impure character occur in the Lias, Oolite, and Lower Greensand formations, and are found almost continuously from the northern parts of Wiltshire to the Wolds of Yorkshire, passing through Oxfordshire, Northamptonshire, and Lincolnshire. This ore usually presents the appearance of a brown ferruginous oolitic rock, which has sometimes a greenish tinge when freshly broken. The most important of these deposits is that at the base of the Inferior Oolite (zone of *Ammonites murchisonicæ*), which extends from the neighbourhood of Banbury through Northamptonshire. These ores, although of low quality, admit of being raised at a very cheap rate, and besides being smelted upon the spot, are largely exported to Staffordshire and South Wales. The ferruginous beds, which usually rest directly on the Upper Lias Clay, are the equivalent of the Dogger of Yorkshire, the good ore seldom exceeding from eight to ten feet in thickness. The Northamptonshire sand is worked for iron ore at Blisworth, Duston, Wellingborough, Cogenhoe, Glendon, Finedon, Gayton, Brixworth, Woodford, Islip, &c., in Northamptonshire, at Steeple Aston and Heyford in Oxfordshire, and at Neville Holt in Leicestershire.[1]

Although the larger proportion of the Northamptonshire iron ores are essentially hydrated peroxides of iron associated with sand, scales of mica, and sometimes a few minute spherules of magnetite, a certain amount of carbonate of iron is also generally present. The inner portions of concretionary masses of this iron ore often consist, for the most part, of carbonate of iron, while the outside is entirely composed of brown hæmatite, the latter having evidently been derived from the former through the action of atmospheric influences. Analysis shows that the grayish mineral of the Northamptonshire ores contains from 60 to 80 per cent. of carbonate of iron, with from 10 to 25 per cent. of insoluble matter chiefly consisting of sand and siliceous oolitic concretions. Besides

[1] H. Bauerman, *Metallurgy of Iron*, 1882, p. 89.

these, but existing in smaller proportions, are the carbonates of lime and magnesia, with carbonaceous matter, water, sulphur and phosphoric acid. The last of these bodies is, unfortunately for the value of the ore, invariably present, and frequently in considerable quantity.

Mr. S. Sharp has noted the following divisions of the beds in the Northampton district—[1]

	Feet.
4.—White or gray sand and sandstone, sometimes quarried as building-stone, containing a plant-bed	12
3.—Thin ferruginous sandstone and shelly ferruginous beds, very variable, being sometimes entirely calcareous, at others consisting of white sand and sandstone	30
2.—Coarse oolitic limestone	4
1.—Ironstone beds containing *Rynchonella variabilis, R. cynocephala, Ammonites bifrons, &c.*	35
Upper Lias clay.	

At Banbury the beds are only twelve feet in thickness.

The Northamptonshire sands include the lower estuarine series of Professor Judd, which comprehends the brown and white sands with argillaceous beds and plant-remains occurring above the fossiliferous beds of ironstone. It would appear from the investigations of this geologist that, although in the southern part of Oxfordshire and in South Northamptonshire the Northampton sands are the equivalent of the lower zone of the Great Oolite and of part of the Inferior Oolite, in the northern part of Northamptonshire and in Lincolnshire they include the lower estuarine series, and occur beneath the Collyweston slates and Lincolnshire limestone of the Lower Oolite. In Wiltshire the same ore occurs in the Coral Rag, and in Buckinghamshire in the Lower Greensand. In the latter locality the bed is not continuous, but nodular masses of limonite are scattered through a stratum of brown sand about fifty feet in thickness. The nodules of ironstone are frequently hollow and enclose loose white sand. After a careful study of the district, Professor Judd has arrived at the following conclusions relative to the origin of the sands and iron ores of Northamptonshire:[2]

[1] "The Oolites of Northamptonshire," *Quart. Jour. Geol. Soc.* xxvi. 1870, p. 354.

[2] "Geology of Rutland," *Mem. Geol. Survey*, 1875, p. 136.

"We find in what is now the midland district of England, and at a period separated by a long interval of time from that of the last deposit in the area, the Upper Lias clay, that a number of considerable rivers, flowing through the Palæozoic district lying to the north-west, formed a great delta. Within the area of this delta the usual alternations of marine, brackish water, and terrestrial conditions occurred, and more or less irregular accumulations of sand or mud in strata of small horizontal extent took place. Subsequently, and probably in consequence of the gradual depression of the area, the conditions were changed, and in an open sea of no great depth, by the abundant growth of coral reefs and the accumulation of dead-shell banks, during enormous periods of time, the materials of the great deposits of the Lincolnshire Oolite limestone were formed. On a re-elevation of the area the former estuarine conditions were also reproduced, and similar deposits, but of an argillaceous rather than an arenaceous character, were formed. Confining our attention to the earlier of these two estuarine series, that of the Northampton sand, we must imagine the beds as being carried down to great depths in the earth by the deposition upon them of the superincumbent strata. But at the same time another most important cause has come into operation, namely, the passage through some portions of the rock of subterranean water containing carbonate of iron in solution. By this agent, carbonate of iron was deposited in the substance of the rock, while portions of the siliceous and other materials were dissolved; and these entering into new combinations, were in part re-deposited in the mass of the rock in the form of oolitic grains, and in part, probably, carried away in solution. During the existence of the beds under a great pressure of overlying rocks, they would likewise become consolidated and jointed. These metamorphic processes would probably take place with extreme slowness and may possibly be still going on, where the rock remains deep seated in the earth; by their means, portions, greater or less, of the sandy strata, but always those resting immediately on the impervious Upper Lias clay, would be gradually converted into solid and jointed rock beds, composed principally of carbonate of iron. The next stage in the course of alteration in these rocks would commence when, by the action of denudation, portions of them were brought again near the surface so as to be traversed by the atmospheric waters entering them as rain, and passing away from them as springs. The action of this water is, as we have seen, to remove the carbonic acid and soluble salts, to change the protoxide of iron into hydrated peroxide and to re-distribute it in such a manner as to produce the remarkable cellular structure of the rock, and also the mamillated, botryoidal, and sculptured surfaces. Finally, by mechanical, as distinguished from chemical, sub-aërial denudation, the beds of Northamptonshire iron ore nearest the surface were disintegrated and broken up, and the softer and less ferruginous portions to some extent carried away in suspension, and thus deposits composed of the harder and denser materials formed, constituting the bed usually worked as an iron ore."

The history of the working of the ores from the Oolite of the Midland district is a somewhat remarkable one. There is evidence that as long ago as the Roman occupation of the country these beds of iron ore were extensively worked, since in a wood near Oundle heaps of broken ore, piles of the same ore after calcination, and very large quantities of slag are found associated with Roman coins and pottery. It is further known, from existing documents, that during later times Rockingham Forest vied with the Weald of Kent and Sussex as an iron-producing district. In both these areas the presence of beds of iron ore in the close proximity of an almost unlimited supply of timber had, at an early date, led to the erection of numerous forges of the kind then employed for the manufacture of iron. Throughout nearly the whole of the Northamptonshire district large accumulations of rich iron slags are still met with. They are dark in colour, very heavy and compact, and apparently contain a large proportion of the iron originally present in the ores treated.

The re-introduction of the Northamptonshire ore into the iron trade is of comparatively recent date, and is principally due to the exertions of Mr. S. H. Blackwell, of Dudley. In the year 1851, Dr. Percy directed the attention of this gentleman to a specimen of iron ore which he had received from the district in question. Mr. Blackwell thereupon inspected the locality, and his investigations resulted in the discovery of an extensive deposit of ore, the importance of which to the iron trade of the present day is very great.

In Lincolnshire, iron ore occurs in the Lower Lias limestones and shales characterised by a great abundance of *Gryphœa arcuata*. The ironstone bed, which is 27 feet in thickness, is worked at Scunthorpe and Froddingham in the northern part of the county. Two beds of ironstone, measuring respectively four and eight feet in thickness, are met with in North Lincolnshire, and are probably the equivalent of some of the Cleveland ironstones. The Marlstone rock yields a good ironstone in some parts of South Lincolnshire, and evidence still exists of its having been formerly worked.

The Northampton-sand ores were in former times extensively dug in South Lincolnshire, but at the present time no workings in this formation are being anywhere carried on within the limits of the county.

The Ironstone Junction Bed at the base of the Upper Estuarine series, the equivalent of the Stonesfield Slate of the South of England, is a band of good ironstone about a foot in thickness, which has been worked at various times, although not recently. A few years since a considerable amount of ironstone in the form of balls was obtained from the Great Oolite clay at Overton, near Peterborough, but the workings have been abandoned in consequence of the large amount of waste material it was found necessary to remove.

In the beds of the Tealby series, Middle Neocomian, is found a brown oolitic ironstone in a bed averaging nearly six and a half feet in thickness; this ore closely resembles that worked near Salzgitter in Hanover, and is of the same geological age. Fossils are extremely numerous in this deposit, and the ore, which is highly calcareous, contains from 28 to 33 per cent. of iron. It is much used for mixing with certain clay ironstones from Yorkshire.

The Upper Sandstone Shale and Coal of Professor John Phillips, probably of the age of the Great Oolite, contains, in Yorkshire, bands of ironstone in nodules, some of which have been formerly worked. The Lower Sandstone Shale and Coal of the same author, equivalent to the upper part of the Inferior Oolite, also contains similar nodules.

The celebrated ironstone of Cleveland occurs in the Middle Lias, and is divided by bands of shale and pyrites into several beds. Where best developed it has a total thickness of above twenty feet, the two principal beds being known respectively as the *Pecten* and *Avicula* seams, from the prevalence in them of fossil shells belonging to the same genera. There can be little doubt that the ore bed has been formed by metasomatic replacement of a bed of limestone.

The usual colour of the ore is a dull bluish-green, arising from the presence of silicate of iron; its structure is oolitic with numerous interspersed fossils. As raised from the mine these ores contain from 29 to 32 per cent. of iron, and the beds worked extend, inland, from Redcar to Eston near Middlesbrough on Tees. At

Eston the main bed attains its greatest thickness, presenting in some places a section of nearly twenty feet of undivided ironstone. From Eston the bed gradually, but slowly, thins off towards the south-east, but in the opposite direction this takes place more rapidly. The whole of the workable Cleveland ironstone is in the highest part of the Middle Lias, the yield per acre varying from 20,000 to 50,000 tons.

The upper seam is, as a rule, too siliceous to be worth working; about the only place where it has been worked regularly is at Rosedale Abbey. Practically the whole of the ore known as Cleveland ironstone is derived from the lower or main seam. Though its thickness, as stated above, is nearly twenty feet at Eston, its average thickness is from eight to ten feet[1] (9ft. 6in. in the Lumpsey mines) in the northern part of the bed in the neighbourhood of Saltburn, at which place the seam is some ninety-four fathoms below the surface and some fifty below sea level. There is here a thin parting in the seam which becomes thicker on going south till it is thirty-one feet thick in the valley of the Esk.[2] The following is the average composition of Cleveland ore as given by Sir Lowthian Bell:—

	Per cent.
Iron protoxide	39·92
Iron peroxide	3·60
Manganese protoxide	0·95
Alumina	7·86
Lime	7·44
Magnesia	3·82
Carbonic acid	22·85
Phosphoric acid	1·86
Insoluble matter, &c.	4·58
Silica soluble in acid	7·12
	100·00

The "Dogger" includes the lower part of the Inferior Oolite and the sands below it; and in some places, as at Rosedale, these form a rich iron ore. This ironstone, which is magnetic and polar, sometimes contains as much as 50 per cent. of iron, and has a greenish, blue, or black colour, with the imperfect oolitic structure observable in unweathered specimens of Northampton-sand ore.

The production of iron ore in the Cleveland district during the year 1881 amounted to 6,538,471 tons.

[1] A. L. Steavenson, "The last twenty years in the Cleveland Mining District," *Journal Iron and Steel Inst.* xliv., 1893.

[2] Sir Lowthian Bell, "On the American Iron Trade," *ibid.* 1890, p. 119.

That of Northamptonshire was 1,270,544 tons; of Lincolnshire, 1,021,506 tons; of Wiltshire, 39,222 tons; and of Oxfordshire 8,614 tons.

The production was as follows in the years 1890 and 1894:—

	1890. Tons.	1894 Tons.
Cleveland	5,617,573	5,048,966
Northamptonshire	1,278,381	1,130,773
Lincolnshire	1,052,409	1,554,286
Wiltshire, Oxfordshire	143,339	155,407[1]
Leicestershire	968,479	568,026

SHROPSHIRE.—Shelve, a remote parish in the western part of Shropshire, is situated in the centre of a tract of country where Silurian strata of Llandeilo age are prominently developed. Although the stratified rocks in the district around Shelve principally belong to the Llandeilo formation, they are to some extent surrounded by a fringe of Upper Llandovery and Wenlock deposits, which repose unconformably upon them. On the east, the Llandeilo and the Lingula Flags rest on the Cambrian strata of the Longmynd range.[2]

The strata of the Lower Llandeilo series are of a very uniform character, consisting of fine-grained shales which vary considerably in hardness, but which never present any indication of slaty cleavage. When first brought to the surface out of the mines the fracture of this rock exhibits a massive slaty character, but after being for some time exposed to the action of the atmosphere, it splits along its planes of bedding, and assumes the appearance of a shale. At the surface is principally a soft, splintery shale, but in the vicinity of the numerous greenstone dykes it frequently becomes a hard slaty rock. Generally speaking, the strata are nearly black, although shales of a light shade occur with less frequency; while in certain localities thick flagstones are interstratified with the other rocks. The lead veins of the Shelve district have probably been worked, at various intervals, from a period shortly after the Roman occupation of Britain, as the discovery of pigs of lead bearing the inscription of IMP. HADRIANI AUG. shows that, at the Roman Gravels Mine, ore was being raised and smelted early in the second century of the Christian era. The only extensive ancient excavations are those at the Roman Gravels Mine, which still continues to be the most productive in

[1] Including Rutlandshire and Somersetshire.

[2] G. H. Norton, "The Geology and Mineral Veins of the Country around Shelve, Shropshire," *Proc. Liverpool Geol. Soc.* September, 1869.

the district. These openings originally consisted of three cuttings following the course of the Sawpit, Roman, and Second North Veins, and extending in the form of furrows up the hill side and over its crest. Those on the outcrops of the two first named veins are still distinctly traceable, but that on the Roman Vein is by far the most important excavation. In its present condition, this presents the appearance of a deep trench extending up the side of the hill, continued over the top, and, finally, ending in a series of shaft-like openings, of which the mouths have generally fallen together. At the end of the main opening, which is about 100 fathoms in length, the lode has been followed underground, and its contents worked out. The width of the vein, where it is visible, is from two to six feet, and the open workings on the back vary from twenty-five to fifty feet in depth. Lower down in the mine the width of the lode varies from six inches to ten feet. Immediately beneath the point at which the ancient miners finally suspended their operations, a large mass of galena was found.

There are five different lodes at this mine, all of which are comprehended within a strip of ground not exceeding 370 yards in width; these are named, respectively, the Spring, Sawpit, Roman, First North, and Second North Veins. The Second North and Roman Veins run nearly parallel to one another; both having a direction N. of W. and S. of E., with a dip towards the N.E. The First North, the Sawpit, and the Spring Veins are also nearly parallel, but take a more westerly course. The First North Vein has a S.W. dip, while that of the other two is in a contrary direction. Both the Sawpit and Spring Veins are intersected at a small angle by the Roman Vein. The lodes are to a large extent composed of calcite with a certain amount of quartz, and in addition to galena they contain blende and iron pyrites; but few druses are found in them, and well crystallised minerals are of rare occurrence. At the Oven Pipe Mine in this district the lode sometimes contains small cavities enclosing bitumen.

The Roman Vein was by far the most important, and, in modern times, has yielded fully seven-eighths of all the ore which has been raised from the mines. It was quite recently still producing a considerable quantity of lead at the depth of 100 fathoms below the surface. None of the veins have ever been worked more than a few fathoms beyond the road leading from Bishop's Castle to Minsterly, as the strata there change from a hard slaty rock into a soft shale, in which they die out. A dyke of eruptive rock traverses the Roman Vein and hardens the rock in its vicinity. This vein has been followed in a south-easterly direction, and was lost in soft shales as at the other extremity.

During the year 1881 the Roman Gravels Mine produced 2,921 tons of lead ore, of the value of £28,109; its production has, however, diminished terribly since then; in 1894 it was only returned at eight tons, valued at £50. In the same year it produced, however, over 100 tons of zinc ore, valued at £400.

Next after the Roman Gravels, the most important mine of the Shelve district is Snailbeach. This, which is a very old working, situated to the north of the Gravels Mine, has been wrought for a long period, and, after having been with the Bog Mine, now abandoned, the richest in the neighbourhood, still yields a considerable annual return of lead, and is now in 1895 the leading mine of the district.

The workings are exclusively confined to one large lode, although the existence of another to the south of it, and consequently called the "South Lode," has been satisfactorily established. The country rock is a hard, quartzose, slightly micaceous schist, of a greenish-gray colour, and of Llandeilo age, which dips W.N.W. at an angle of 60°, conformably with the Stiperstones; the strike of the bedding ranges N. of E. and S. of W., parallel with the Longmynd system. In the western part of the mine there are alternations of soft shale with the harder rocks.

The average bearing of the lode is nearly true E. and W., but for short distances it varies considerably from this course. It crops out in the side of a hill facing the north, under which it dips with a tolerably regular underlie of two feet in a fathom; its richest portions usually bearing nearly E. and W. The levels on the course of the lode are fifteen fathoms apart, and are connected with a shaft about 200 fathoms in depth by cross-cuts. In length the workings have been extended 400 fathoms east and 200 fathoms west of the shaft.

The line of junction between the lode and the bedding of the strata dips west at an angle varying from 45° to 55° with the horizon; this is precisely the dip of the shoots of ore, which are remarkable for their regularity. A section showing the general arrangement of the shoots of ore in this lode is given in Fig. 43, page 94. Six principal shoots of ore have been discovered at Snailbeach, and at a point west of the shaft the ore was, in one level, as much as 75 fathoms in length; still further west, the alternations of soft shale with micaceous schist correspond with the complete impoverishment of the lode, which becomes of no value in these soft bands. In its richer portions its width sometimes reaches ten feet, but when passing through shale it is usually very small as well as unproductive.

The principal constituents filling the vein fissure are calcite, which is often well crystallised, and forms a large portion of the veinstone, quartz, which is not of common occurrence, and is chiefly found where the vein is enclosed in a hard siliceous rock, and fragments of country rock, which are often enclosed in the vein. Its metalliferous constituents are galena, both fine-grained and in large facets, both varieties being poor in silver, blende of two kinds, one compact with a brown colour, and the other fibrous, and of a yellowish hue, together with ordinary iron pyrites. Bituminous matter has been found in small nests in the Snailbeach lode, and the same substance abounds in a vein, which was worked some seventy years ago, near Pontesbury. At Snailbeach the lode even in its richest parts affords but a small proportion of massive ore, and consequently nearly the whole of the lead-producing material brought to the surface is subjected to the operations of crushing and washing. The yield of the Snailbeach mine for the year 1881 amounted to 1,946 tons of lead ore, of a value of £18,500. The quantity was not very different in 1894, being 1,855 tons, but owing to the heavy fall in the price of lead (£10 2*s.* 2*d.* per ton as against £15 11*s.* 6*d.*) the value was only £11,075. The mine also produced 20 tons of zinc ore. The total amount of lead ore raised in Shropshire in that year was 2,057 tons.

CHESHIRE.—The copper mines of Alderley Edge and Mottram St. Andrews are situated in Cheshire, about four miles north of the town of Macclesfield. The escarpment or "Edge" at Alderley rises gradually from the eastern side of the plain of Cheshire towards the east, but forms an abrupt ridge towards the north. This ridge has been upheaved along the line of a large fault bearing east and west, and throwing down the Red Marl on the one side, and on the other bringing up the soft sandstone of the Bunter, capped by a wall-like escarpment of Lower Keuper conglomerate which often breaks out conspicuously from among the trees with which the side of the hill is covered. The beds rise from the plain towards the east at an angle of from 5° to 10°, and the escarpment is continued for some distance southward facing the east.

The general form of the Edge and its component beds is shown in Fig. 75, after an illustration of Professor Hull, who first determined the true horizon of the copper-bearing sandstones of this locality.[1]

SUCCESSION OF BEDS IN DESCENDING ORDER.

M. Red marl		Red and gray laminated marls.
b^4 *Waterstones*	Lower Keuper sandstone 500 feet.	Brownish flaggy sandstones and marl.
b^3 Freestone		White and brown freestone.
b^2 Copper-bearing sandstone		Soft white, yellow, and variegated sandstone.
b^1 Conglomerate		Hard quartzose conglomerate, underlain by bands of marl, forming the base of the Keuper series.
a Upper red and mottled sandstone	Bunter.	Soft, fine-grained, yellow and red sandstone, being the uppermost member of the Bunter sandstone.

The metalliferous beds are those marked b^1 b^2 at the base of the Keuper series; the former of these, besides containing ores of copper and other metals, is somewhat remarkable for its petrological peculiarities. It consists, generally, of a whitish, firmly-

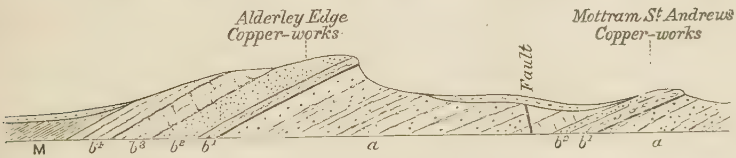


FIG. 75.—Section from Alderley Edge to Mottram St. Andrews.

cemented conglomerate chiefly composed of well-rounded pebbles of quartz, in all respects similar to those which occur so constantly in the Pebble-beds of the Bunter. Copper, in the form of green and blue carbonates, is disseminated throughout the cementing material of this rock, at Alderley Edge to a very small extent only, but in considerably larger quantities at Mottram St. Andrews, about a mile to the north-east of the Alderley Edge workings. The position of the conglomerate at Mottram, so far below and beyond the base of its contemporaneous beds at Alderley, is due to the great east and west fault already referred to, which throws down the beds to the north. The conglomerate is here exposed in a quarry, in which, twenty-five years ago, copper was first discovered in the district. For some years systematic mining was carried on in this locality, the copper-bearing material being removed through a series of numerous shallow shafts. The results

[1] Edward Hull, "On the Copper-bearing Rocks of Alderley Edge, Cheshire,' *Geol. Mag.*, i. 1864, p. 65. E. Hull and A. H. Green, "The Geology of the Country around Stockport, Macclesfield, Congleton, and Leek," *Mem. Geol. Survey*, 1866, p. 39.

obtained were, however, commercially unsatisfactory, and the workings were therefore abandoned.

The beds formerly worked at Alderley lie above the band of conglomerate, and are marked b^2 in the section. The impregnation of copper minerals is confined to a breadth of some forty to fifty feet, in three beds of sandstone, and beyond this width the cupriferous impregnations rapidly die out on either side. The sandstone, which exhibits a uniformly soft texture, is stained along a series of imperfectly defined layers which are variously coloured green, blue, red, or brown, in accordance with the nature and state of combination of the metals present in largest quantity. In addition to copper these sandstones contain sulphate of barium and small quantities of lead, manganese, iron and cobalt. The lead is present chiefly in the form of cerussite, but galena, pyromorphite and vanadinite are also met with.

The lowest of the three metalliferous beds is sometimes as much as sixty-six feet in thickness, but it varies considerably in this respect; it dips at an angle of about 12°, and it has been worked downward for a distance of about 300 fathoms.

Above this, which is known as No. 1 bed, lies a seam of clayey sandstone, varying in thickness from one foot to six feet, and upon this rests the metalliferous bed No. 2, which is 18 feet thick and covered by about twelve feet of red clayey sandstone. Above this sandstone is bed No. 3, also 18 feet in thickness, but which has not been extensively worked. The section of the beds in 1864, at the face of the workings, was as follows :—[1]

	Fathoms.
Surface clay and red sandstone . . .	17
No. 3 bed	3
Red clayey sandstone	2
No. 2 bed	3
Blue clayey sandstone	1
No. 1 bed	11
	Total 37 fathoms.

The average amount of copper contained in the workable portion of the metalliferous sandstone is about 1·4 per cent., with traces of cobalt.

[1] G. C. Greenwell, "On the Copper Sandstone of Alderley Edge, Cheshire," *Proc. S. Wales Inst. of Engineers*, iv. 1866, p. 44.

These mines were worked for many years with considerable success, but the lease having expired in 1877 and the yield of copper having somewhat fallen off, the workings were suspended and have not since been resumed. At this mine, the copper-bearing sandstone was drawn up an inclined plane, by a drum attached to the main shaft of an engine connected with a Cornish crushing mill. After having been coarsely ground, without sifting, the sand was taken to a number of tanks with perforated false bottoms, in which it was treated with dilute hydrochloric acid. Filtering rapidly through the ground sandstone the dilute acid collected in the chamber beneath the false bottom, from which it was constantly pumped and distributed over the surface of the ore. The pumping was continued until the whole of the soluble copper salts had been dissolved, the metal being afterwards precipitated by the introduction of scrap iron into the liquors drawn off into suitable receivers. The resulting copper precipitate was sold to copper smelters in the usual way.

The liquors containing ferrous chloride, from which the copper had been removed, contained a small amount of cobalt, and an attempt was made to recover that metal in the following way. The spent liquors from the precipitation of copper were run off into a large reservoir, where, after having been allowed to oxidise by exposure to the air, milk of lime was added. The precipitate thus produced contained arsenic as well as cobalt, and was smelted for speiss in a reverberatory furnace. The results obtained were, however, not satisfactory.

An attempt was also made to render available the lead ores contained in certain bands of the sandstone which, for the most part, are distinct from those yielding the bulk of the copper ores. With this view the more plumbiferous sandstones were ground between burr-stones, and subsequently washed. A very large proportion of the ore, which is chiefly cerussite, was, however, found to float away in suspension in the water, and after numerous trials it was found that the loss of lead incident on bringing the ore up to a produce of 45 per cent. was so great, that it became necessary to abandon the process.

Lead Mines of the Carboniferous Limestone.—The lead mines of the extreme north of England are situated in the counties of Northumberland, Durham, Cumberland, and Westmoreland. The surface of this portion of Great Britain varies in character from extensive plains to mountains of considerable height, exhibiting in some places a richly wooded and fruitful soil, while in others little is to be met with but barren hills, with more or less extensive pasturage in the valleys.

Beneath the comparatively flat land in the approximate vicinity of the eastern and western coasts the upper members of the Carboniferous series contain valuable seams of coal, and from beneath these rise the *Lead-measures*, consisting of various members of the Carboniferous limestone. They rise gradually towards the west with an inclination greater than that of the general slope of the country, so that they successively reach the surface over a large area, attaining their highest elevation in the mountain of Cross Fell, Cumberland. Similar outcrops occur in adjacent fells, or elevated moorlands, and these, extending in a north and south direction, form the western limit of the lead-mining districts of the north.

The lofty range of elevated land constituting the Pennine Chain, extends from Derbyshire to the Cheviots, and occupies a ridge of from twenty to thirty miles in width, forming the central portion of the north of England. It sometimes attains a height of 2,000 feet above the level of the sea, and is formed of a broad anticlinal curve, which is much broken by large faults along its north-west flank towards Westmoreland and Cumberland, as well as along its western margin extending into Staffordshire. On the opposite side, throughout Yorkshire and Derbyshire, the beds are less disturbed, and usually dip at a moderate angle beneath the coal-measures. In many parts of this range are numerous and extensive lead mines, which may be classified into the following groups :—[1]

1st.—Mining districts connected with the River Tyne, and its tributaries, the Nent, the East and West Allen, and the Derwent; namely, Alston Moor in the county of Cumberland, East and West Allendale in the county of Northumberland, and the Blanchland and Derwent Mines in the same county. In addition to these, which are distinct mining areas of considerable extent, there are other valuable lead mines, situated in isolated localities, some of which are extensively worked, in the Valley of the Tyne.

2nd.—The extensive mining district of Weardale, occupying all the upper part of the valley of the River Wear and its tributary valleys of Burnhope, Killhope, Wellhope, Treshope, Rookhope, &c.

[1] T. Sopwith, "On the Lead Mining Districts of the North of England," *Trans. N. Eng. Inst. Min. Eng.* xiii. 1864, p. 188.

3rd.—An extensive district in and adjoining Teesdale, the mines being situated chiefly in the valley of the River Tees, and in adjacent portions of Yorkshire and Westmoreland.

The maximum thickness in the north of England of the Carboniferous or Mountain Limestone is about 2,800 feet, which is made up of alternating strata of limestone, sandstone, and shale, while between them is interposed one thick layer of trap. The upper members of the series appear at the surface, on the sides of the upper valleys of the South Tyne, Wear, and Tees, forming the rocks in which the lead veins of those districts are enclosed. At Alston Moor, one of the principal mining centres of this part of the country, the aggregate thickness of the Carboniferous limestone series does not exceed 1,037 feet, and consists of 183 feet of limestone, 349 of sandstone, and 505 feet of Shale.

The trap rock, or *Whin Sill*, which crops out at the surface in two or three places only, may, at Alston Moor, be regarded as forming the base of the metalliferous beds; the lower portion of the Mountain Limestone is, however, visible at the surface on the western escarpment of Cross Fell.

The table on page 272, constructed by Mr. Wallace, shows the composition and total thickness of the Millstone Grit and Mountain Limestone rocks in Alston Moor and the adjoining mining districts.[1]

In the Alston district it is unusual for any member of the series to be altogether wanting, but in the Tee-side and Troutbeck mines the strata above the Whin Sill vary considerably, both in thickness and in the order of their succession, from those found in the mines near the River Tyne. In the Tees-side district a greater thickness intervenes between the top of the Whin and the bottom of the Scar Limestone than at Garrigill on the Tyne, but in the latter the Whin is very considerably thicker than in the former, and the distance in each case between the bottom of the Whin and the bottom of the Scar Limestone is nearly equal.

The veins of the north of England may be grouped into three classes, namely, *veins*, *cross-veins*, and *quarter-point veins*.

The first class, sometimes called *rake veins*, or *right-running veins*, comprehends all those coursing approximately east and west but varying in direction between N. 60° E. and S. 60° E. Veins

[1] W. Wallace, *The Laws which Regulate the Deposition of Lead Ore in Veins*, London, 1861, p. 17.

General Section of the Millstone Grit and Mountain Limestone Rocks as Developed in the Alston Moor and adjoining Mining Districts.

No.	Local Names.	Sandstone.		Shale.		Limestone.	
		ft.	in.	ft.	in.	ft.	in.
1	Coal (Brockwell's)						
2	Slate	15	0	3	2		
3	Girdle Beds			48	0		
4	Freestone	52	0				
	Coarse Hazle Girdle Beds			37	0		
5	Millstone Grit	27	0	27	0		
6	Hard Hazle[1]	9	0	9	0		
7	Freestone	45	0	6	0		
	Gray Beds	15	0				
8	Hazle	10	6	44	6		
9	Alternating Gray Beds			88	0		
10	Grindstone Sill	24	0	33	0		
11	Hazle and Coal	9	8	10	0		
12	Fell-top limestone					4	6
13	Hazle	12	0	30	0		
14	Do.	9	0	12	0		
15	Do.	12	0	7	0		
16	High Slate Sill	24	0	7	6		
17	Low Slate Sill	21	0	22	0		
18	Fiddler's Sill	15	0	30	0		
19	Ironstone and Coal	4	6				
20	Firestone	30	0				
	Girdle Beds			66	0		
21	Pattinson's Sill	12	0	24	0		
22	Little Lime and White Hazle	5	0	9	0	6	0
23	High Coal Sill	14	0	6	0		
24	Low Coal Sill	12	0	26	0		
25	Great Limestone					63	0
26	Tuft	9	0	16	0		
	Limestone post					1	3
27	Quarry Hazle	30	0	37	6		
	Till Bed						
28	Four Fathoms Limestone					24	0
29	Nattrass Gill Hazle	18	0	66	0		
30	Three Yards Limestone					9	0
31	Six Fathoms Hazle	36	0	10	6		
32	Five Yards Limestone					15	0
33	Slaty Hazle	12	0	18	0		
34	Scar Limestone					30	0
35	Alternating beds { *High Copper Hazle* *Cockleshell Lime* *Low do. do.* *Post Lime* *Tyne-bottom Plate* }	35	0	90	0	14	0
36	Tyne-bottom Limestone					24	0
37	Whetstone Bed	6	0				
38	Whin Sill	120	0	9	0		
39	Hazle	10	0	11	0		
40	Do.	11	6	3	0		
41	Do.	18	0	9	0		
42	Jew Limestone			7	0	24	0
43	Slate	15	0	4	6		
44	Little Limestone			15	0	18	0

[1] Hazles are compact sandstones.

General Section of the Millstone Grit and Mountain Limestone Rocks as Developed in the Alston Moor and Adjoining Mining Districts—(*continued*).

No.	Local Names.	Sandstone.		Shale.		Limestone.	
		ft.	in.	ft.	in.	ft.	in.
45	Hazle	51	0	24	0		
46	Smiddy Limestone					31	6
47	Hazle	12	0				
48	Limestone			4	6	25	6
49	Hazle	12	0	5	0		
50	Robinson's Lime					21	0
51	Hazle	9	0	3	0		
52	Scar Limestone			12	0	132	0
53	Freestone	6	0	6	0		
54	Limestone					12	0
55	Freestone	105	0	9	0		
56	Do.	7	6	9	0		
57	Do.	7	6	9	0		
58	Do.	9	0	9	0		
59	Limestone					7	6
60	Hard Freestone	12	0	42	0		
61	Seven-inch Coal with Plate			129	7		
62	Freestone	30	0	7	6		
63	Limestone					18	0
64	Freestone	174	0	60	0		
	Totals	1133	2	1171	3	480	3

belonging to this class are usually metalliferous, and are more frequently productive when enclosed in hard rocks, particularly in limestone, than when their walls consist of shale or of some other soft material.

The second class comprises all veins whose direction is nearly north and south. They usually displace those belonging to the first class, and are less variable in their course. In the strata above the Great Limestone they are rarely metalliferous, and seldom even contain any considerable amount of veinstone. In the Great Limestone they have, in the aggregate, yielded large quantities of galena, while in the strata beneath it they frequently produce ores of both lead and copper.

The veins belonging to the first two classes, which cross one another nearly at right angles, are sometimes intersected by a class of smaller veins having an intermediate bearing and hence called *quarter-point veins*, the "point" of a vein being the local term indicating its bearing. These intermediate veins traverse the country in two different directions, the one being S. 55° E. and the other S. 55° W. Like the veins of the second class they contain but little veinstone in the beds above the Great Limestone; in the strata below it, however, they are often filled with iron pyrites, copper pyrites, calcite, &c. They seldom contain lead ore.

Veins of all classes have in this district usually been formed along lines of fault. The "throw" is the term locally employed to signify the vertical disruption which generally occurs along the course of the more considerable veins. The perpendicular distance between the corresponding strata on the opposite sides of the same vein varies in Alston Moor from a few inches to 300 feet, and there is, moreover, a remarkable correspondence between the dip and throw of veins, which, although not without exceptions, is nevertheless very general.

Following the general rule of normal faults that the hanging side of the fault has moved downwards, or, as expresed in the north, that the fault hades to its downthrow, if an east and west vein throws the strata up on its south side the dip or hade will generally be towards the north, and *vice versâ*, the dip being usually opposite the side on which the strata are highest. Mr. T. Sopwith gives the following instance of the variable throw of the same vein in different localities, as exemplified by Old Carr's Cross-vein in Alston Moor. This powerful vein throws up the strata at—[1]

Middle Cleugh Second Sun Vein . .	42	feet.
Middle Cleugh Vein	48	„
Carr's Vein	60	„
Broomsberry	72	„
Nentsberry Greens	162	„

In the Alston Moor district a vein is said to be *weak* when the strata on either side are but slightly displaced, and *strong* when the difference of level between similar strata is considerable. In addition to the difference in the level of corresponding strata which so frequently occurs on the opposite side of a vein, the veinstone itself is sometimes traversed by a longitudinal fissure with well defined slickensides upon its faces. In the upper parts of Alston Moor, the quarter-point veins are usually small and their throw only a few inches, the largest, which is about six feet, occurring at the Nenthead Mines. In the lower part of the field, the veins belonging to this class are much stronger, and one of them in the Rodderup Fell Mine, throws up the north-west side no less than forty feet.

[1] *Mining District of Alston Moor, Weardale, and Teesdale*, Alnwick, 1833, p. 107.

The very remarkable fault known as the Great Sulphur Vein traverses the country in a westerly direction for a distance of nearly eight miles, from Hard Rigg Edge, Melmerby Fell, where it terminates against a S. W. fault, to the neighbourhood of Burnhope Seat on the borders of Durham, where it breaks up into a number of comparatively small branches which again unite near Hiddenhole Mine. Westward of this point it intersects a vein which has been worked in the Sir John Mine. After penetrating the Sulphur Vein, which was no less than 180 feet in width in this place, the miners found the Sir John Vein to have been shifted horizontally 20 fathoms. The high level on the north side of the Sulphur Vein is driven in the plate overlying the Scar Limestone, while on the south side it is in the shale under the Cockleshell Limestone, indicating a vertical displacement of about 100 feet.

A little further west the Sulphur Vein is seen on the banks of the South Tyne a little below the Tynehead Smelt Mill, which is built on the Whin Sill, through which the river has cut a narrow gorge terminating in a waterfall of about forty-six feet in height. The Whin Sill abuts against the Sulphur Vein, which on the north side throws in the Tyne-bottom Limestone, which again forms the bed of the river.[1]

This vein is mainly composed of iron pyrites in a matrix of quartz, with here and there large masses of pyrrhotine, the latter containing a small proportion of nickel and a trace of cobalt. The low level in the Sir John Mine has also been driven through the Sulphur Vein, which was found to consist of enormous masses of iron pyrites containing a little copper. Copper ore occurs in the Sir John Vein, as well as in several others in Tynehead, in strata ranging from the top of the Scar Limestone to that of the Tyne-bottom Limestone, but more particularly in the beds known as the Copper Hazles. West of the Tyne the Sulphur Vein crosses a hill called Noonstones, where it consists almost entirely of white quartz, and descending on the other side it is seen in Cross Gill, where it is said to have been at one time worked for gold. At this place the vein consists of a matrix of ferruginous quartz with patches of iron pyrites and pyrrhotine. Still further west it was met with in a mine at Smitter Gill, where masses of pyrrhotine may still be seen on the surface together with fluor spar and other

[1] C. E. De Rance, "On the Occurrence of Lead, Zinc, and Iron Ores in some Rocks of Carboniferous Age in the North-West of England," *Geol. Mag.*, x., 1873, p. 303.

lode stuff derived from lead veins. Many of the veins in this district when poor for lead yield hydrated oxide of iron, and when sufficiently large, are sometimes worked for that ore. On the south side of the Great Sulphur Vein at an average distance from it of nearly a mile, the country is traversed, in a nearly parallel direction, by a trap dyke. No displacement of the strata takes place, and where opened upon by mining operations at its intersection with the Douk Burn Vein no trace of the vein was seen in the dyke, but when the latter had been cut through, the vein was found in its proper position on the other side. It therefore appears that the intrusion of the whin dyke was posterior to the formation of the metalliferous east and west veins of Alston Moor.

In addition to the three classes of veins before described, large quantities of lead ore are sometimes obtained from *flats*, a form of massive deposits that has already been referred to (*see* page 166). Veins, however irregular may be their width, have usually walls or cheeks which maintain the fissure-like character of the opening. In certain members of the lead-bearing strata in this district, however, and especially in the Great Limestone and the Scar Limestone, the veins sometimes branch off laterally into flats which are often very productive. These flats vary as much in their size and characteristics as do the veins themselves. When in the region of flats the miner sometimes cuts into caverns of varying extent, either lined with crystals of calcite, blende, galena, &c., or filled with clay or veinstone. An opening often connects such flats with a vein, and under those circumstances they frequently produce large quantities of ore. Occasionally flats extend over considerable areas and terminate suddenly at a *back* or joint in the strata. Flats situated at a distance from a large vein have often numerous strings or *leaders* running into them; this term being applied by miners, because by following them they are often led to the flats themselves.

The minerals most frequently occurring in the lead veins of this region are quartz, calcite, iron pyrites, blende, galena, fluor spar, and sulphate of barium. In the strata included between the Grindstone Sill and the top of the Little Limestone, the amount of quartz deposited in the veins is less than might have been expected from the generally siliceous nature of the rocks; fluor spar, calcite, and oxide of iron being the prevailing minerals.

In the Little Limestone of the Nenthead district the veins frequently contain much blende and iron ore, and a greater proportion of quartz than is usually found in the sandstones above. Calcite and fluor spar are occasionally met with in this limestone and in the Coal Sills below. Blende is commonly accompanied by quartz, although the converse does not follow, since veins almost filled with this mineral often contain no sulphide of zinc.

In the veins in the Great Limestone a greater variety of minerals is found than in those of any of the strata above. Fluor spar is, however, rarely met with in any considerable quantity in the Nenthead Mines, although it must have been at one time tolerably abundant, as pseudomorphs in quartz after fluor spar are by no means uncommon.

At Garrigill, calcite and fluor spar occur abundantly in the Great Limestone, the veins being in many places almost filled with these minerals. In the Weardale and Allenhead districts the veins in all the strata are chiefly filled with galena, calcite and fluor spar.

In the sandstones below the Great Limestone the east and west veins generally contain more quartz than they do in the strata above. Both the right-running veins and the north and south veins contain much imperfectly crystallised quartz in the Scar Limestone. The veins which have been worked for lead in the Tyne-bottom Limestone often contain much calcite, although quartz is by no means uncommon. In the flats in this limestone beautifully crystallised calcite occurs.

In the Tyne-bottom mines some of the veins have been partially explored in the Whin Sill, where they were found filled with calcite and spathose iron ore, but containing no galena.

The principal veins of the north of England divide the whole of the strata of the Carboniferous limestone series, which are brought variously in opposition to one another by the dislocations usually accompanying vein fissures in that region. Instances have from time to time been recorded of veins being productive under almost every possible circumstance of opposition of the strata, but certain beds have nevertheless long been favourably known for their richness in lead ore. In different mining districts different limestones are thus favourably distinguished, but in the country around Alston Moor, Teesdale, and Swaledale, the Great Limestone is by far the most productive stratum.

In confirmation of this, the following extract relative to the actual quantities of lead ore obtained from all the beds in the manor of Alston Moor, during the year 1822, is given from Mr. J. Taylor's Report on mineral veins:—[1]

Limestone Beds	Great Limestone	20,827 bings[2]	
	Little Limestone	287 ,,	
	Four-fathom Limestone	91 ,,	
	Scar Limestone	90 ,,	
	Tyne-bottom Limestone	393 ,,	
			21,688 bings
Gritstone Beds	High Slate Sill	107 bings	
	Lower Slate Sill	289 ,,	
	Firestone	262 ,,	
	Pattinson's Sill	259 ,,	
	High Coal Sill	327 ,,	
	Low Coal Sill	154 ,,	
	Tuft	306 ,,	
	Quarry Hazle	44 ,,	
	Nattrass Gill Hazle	21 ,,	
	Six Fathoms Hazle	576 ,,	
	Slaty Hazle	18 ,,	
	Hazle under Scar Limestone	2 ,,	
			2,365 bings
	Total		24,053 bings

With regard to the origin of the lead deposits of Alston Moor, Mr. Wallace observes "it would appear that either lead in connection with some basifying principle must enter, in varying proportions, as a component part of the rocks of this district, or some still more elementary substances from which it is formed by laws of chemical combination as yet unknown. I am not aware that the limestones and sandstones of Alston Moor have ever been subjected to careful chemical investigation. If from their analysis it is proved that lead is diffused throughout their whole mass, then the inquiry would be much simplified, and chemists would be able to demonstrate the changes which must be effected in order that sulphide of lead may be deposited in the veins by the agency of circulating waters."[3]

The four most northern counties of England produced, respectively, the following amounts of lead ore, lead, and silver during the year 1881:—[4]

	Lead ore. Tons.		Lead. Tons.	Silver. Oz.
Northumberland, Durham	17,467	=	13,089	54,036
Cumberland	2,376	=	1,720	13,786
Westmoreland	1,236	=	904	11,954

Cumberland also produces annually about 1,800 tons of zinc ores.

[1] *Report Brit. Association*, 1833, p. 1.

[2] Each weighing 8 cwts.

[3] *The Laws which Regulate the Deposition of Lead Ores in Veins*, 1861, p. 242.

[4] R. Hunt, "Mineral Statistics for 1881," *Memoirs of the Geol. Survey*, 1882.

On account of the great fall in the prices of both lead and silver, many previously paying mines could no longer meet expenses, and had to be closed down, whilst mining for these metals has been altogether less vigorously prosecuted in this as in other parts of England during recent years, and there has been a steady diminution in production since 1877. The figures for 1894 corresponding to those given above are as follows:—

	Lead ore. Tons.		Lead. Tons.	Silver. Oz.
Northumberland	1,042	=	743	2,336
Durham	9,214	=	6,438½	59,766
Cumberland	1,750	=	1,289	12,241
Westmoreland	1,461	=	1,040½	13,329

In proportion as falling prices made lead-mining less profitable, more attention has been paid to zinc; in the same year 1894, Cumberland (Alston and Keswick) produced 7,228 tons and Northumberland 10 tons of zinc ores.

The lead-mining district of Yorkshire includes an area of about 700 square miles, and comprehends the high ground bordering Swaledale, Arkendale, and Wensleydale in the north, and Nidderdale, Wharfedale, and Airedale to the south. The rocks of this area, like those of the lead-bearing districts further north, belong to the Carboniferous limestone period, but although they prevail throughout the whole mining area, each individual stratum is by no means everywhere represented, and the thickness of the different beds is exceedingly variable.

The lead ore of the Yorkshire mines is derived from rake veins, pipe veins, and flats. Of these the rake veins are the most productive and important; their course does not usually vary materially from a straight line, but their dip is far from constant. Their inclination from the horizon is less in soft argillaceous beds than in hard solid rocks; while, when passing a thin seam of shale, or soft clay, they often flatten and follow for a considerable distance the inclination of the strata. As is the case elsewhere, the width of the Yorkshire veins is exceedingly variable, frequently opening from one or two feet to several yards, and again contracting to a mere joint. The width of a vein is usually affected by a change of strata, and is greater in hard rocks than in soft ones; it is generally greater in limestone than in sandstone, and in the latter rock than in shale. Rake veins are, in the majority of cases, fault veins, the strata being as a rule lower on the side of the dip than in the contrary direction.

The extent of the throw varies from a few inches to twenty or thirty fathoms; the greatest amount of throw being often observed when nearly parallel veins are in the almost immediate vicinity of one another. The *strength* of a vein is considered to be in direct proportion to the extent of its throw. A vein with a difference of from six to eighteen feet between the height of similar beds on the two sides, is regarded by the miner with more favour than one with either a greater or less displacement. A fault of this extent is looked upon as an indication that a vein has sufficient strength to insure its size and continuity, but is not so great as to destroy the effect supposed to be produced by certain beds when occurring on the same horizon on both sides of a vein. When rocks of a different character form the opposite sides or cheeks of a vein, a deposit of lead ore is rarely found between them; this rule is, however, not without exceptions. At the Grassington Mines, in Wharfedale, there are two veins each throwing the strata, south side down, to such an extent as to cause shale to be opposed to gritstone, shale to limestone, gritstone to limestone, &c., and so on throughout their whole explored depth. Under these conditions one of the veins yielded large quantities of ore, while its neighbour proved totally barren.[1]

When a vein occasions a throw of from two to three fathoms, the ore seldom continues either above or below the change of strata, but is confined to those portions of the fissure which are bounded by the productive rock. An exception to this rule occurred, however, at the Grassington Mines, where a vein produced large quantities of lead ore for considerable distances both above and below such a change of strata. In addition to causing a fault or throw, rake veins materially influence the dip of the strata in the immediate vicinity of their walls. On the side of the more elevated beds the planes of stratification are, for a short distance from the wall, bent downwards, while those on the opposite side are, on the contrary, bent upwards.

Although the veins of this county traverse all the beds of the Carboniferous limestone, there are only certain members of it that usually yield lead ore. In some districts the most abundantly productive strata are limestones, while in others the larger proportion of lead is obtained from the sandstones. The argillaceous shales very rarely produce ore, but even this admits of exceptions, since in the Airedale district lead ores have sometimes been found in these rocks. The great Whin Sill extends into

[1] Stephen Eddy, "On the Lead Mining Districts of Yorkshire," *British Association Reports*, 1858, pp. 167–174.

Northern Yorkshire. In the more northern districts many of the veins have a nearly direct course over a considerable distance. The Old Gang Vein in Swaledale, which has been worked over a length of some miles, and which can be traced in a nearly straight line for a still greater distance, is an example of this persistency of character in lead veins.

The veins of the three northern districts, namely, Swaledale, Arkendale, and Wensleydale, are more regular in size, and the beds more uniform in thickness than they are in the more southern areas. In the former the limestones have been the principal sources of production, while the ores of the southern mines have been chiefly derived from sandstones. Many peculiarities distinguish the mines of the northern districts of Yorkshire from those of the south, and divide them into two distinct classes. Rake veins, pipe veins, and flats are common to both, and it is to be remarked that, on account of the composition of the veinstone with which they are associated, ores from pipe veins and flats are more fusible than those from rake veins. The ores from the limestones are also more easily worked than those from sandstones.

It has been asserted that slickensides never occur in the sandstones of the Yorkshire lead mines, but this is not absolutely correct, since in the Grassington Mines a slickenside was met with in that rock, where, for a distance of nearly seventy yards, it formed the only division between two veins. In both areas, the majority of the lodes are nearly parallel to one another, while the remainder run counter to them and form intersections.

The predominant direction of the principal veins is, in the northern mines, north of east and south of west, while in the southern field it is north of west and south of east. The former known as right-running veins, are, when intersected by the cross-veins, frequently heaved or otherwise affected. In such cases the heave is usually on the side of the oblique angle formed by the intersecting planes of the converging veins. When one or both of the veins have been productive of ore up to the point at which they come together, their yield is, in the majority of cases, increased by their junction. The extent of the angle formed by two veins is, however, regarded by the miner as of much importance, since he considers an acute angle as indicating riches, while a large one is believed to be an unfavourable indication.

Nearly one half of the annual production of lead ore in Yorkshire was in 1880 obtained from Arkengarth Dale, but East

Craven Moor, Keld Heads, and Old Gang are still among the productive mines. The total yield of the Yorkshire mines during the year 1881 amounted to 4,171 tons of lead ore, equivalent to 3,040 tons of lead, and 4,115 oz. of silver.

In 1894 Arkendale and Old Gang mines together produced 430 tons of lead ore, whilst the Pateley Bridge district in the West Riding produced 705 tons, making the total for Yorkshire 1,135 tons of ore, yielding 762 tons of lead, and worth £6,740.

The Carboniferous limestones of Derbyshire rise to the surface over large areas, and are deeply cut into by numerous picturesque valleys, but the base of the series is nowhere exposed. The total thickness of the rocks of this age is about 1,500 feet, and instead of there being one bed of intruded trap, as in the northern counties, there are here three distinct beds of an igneous rock, locally known as *toadstone,* interpolated between four thick beds of limestone.

According to Mr. Wallace, the series of beds comprehended between the top of the Great Limestone and the Grindstone Sill in Alston Moor, corresponds with the Limestone Shale of Derbyshire, the thickness of the two being nearly the same; on the other hand the Millstone Grit, which is fully developed in Alston Moor, will correspond to the Grits of Derbyshire and Wensleydale.

The mineral deposits of Derbyshire comprehend rake veins, pipe veins, and flats, besides which cross-fissures in the limestone, known as *scrins,* sometimes enclose small quantities of lead ore. Few veins are metalliferous either in the Millstone Grit or in the shales, the great majority being profitably worked in the limestone only. When a lode reaches the toadstone, it usually either ceases entirely, or passes through it as a narrow cleft containing no ore. In the limestone beneath the toadstone a vein is sometimes found to have resumed its original condition, but, generally speaking, the workings of the smaller mines are exclusively confined to one bed of limestone.

In 161 out of 180 observed cases, the lode is stated to have entirely disappeared in the toadstone, while in nineteen cases the vein passed through it. As B. v. Cotta however remarks, these results cannot be regarded as altogether reliable, since, from the point of view of a practical miner, a vein which passed through the trap in the form of an unproductive fissure would probably be regarded as having ceased to exist. The prejudicial influence often apparently exercised by this rock upon the production of lead veins, at one time regarded as acting almost universally, has more recently been found not to be without important exceptions. The Mill Close Mine in Darley Dale, which has for some years been the most productive in the county, is worked between shale on one side and toadstone on the other. Some of the rake veins, however, throw the strata, and in such cases it would appear that the vein fissure must have divided all the beds including the toadstones. In some instances the veinstone itself is found divided longitudinally for considerable distances, with the contact surfaces often highly polished. These slickensides are ribbed or slightly fluted horizontally, and sometimes after one side is removed, so as to give room and relieve pressure, fragments fly off, occasionally with loud explosions, and continue to do so for many days.[1] The toadstone, of which there are three beds, is a dark, compact rock, sometimes closely resembling basalt, but more commonly softened by decomposition, and often presenting an amygdaloidal structure.

Each of the beds averages from sixty to seventy feet in thickness, and preserves its course between the strata of limestone for many miles uninterruptedly. It is somewhat doubtful whether these layers of igneous rock are to be regarded as lava-flows contemporaneous with the deposits of limestone, or as subsequent injections into fissures parallel with the stratification. De la Beche regarded them as contemporaneous flows; Sedgwick, on the other hand, believed them to be subsequent injections. Jukes pointed out that each of them is probably the result of not merely one eruption, but rather consists of different flows proceeding from distinct vents and uniting into one sheet along a common floor. The most productive mines have been worked in the First Limestone, and perhaps the least so in the fourth stratum of that rock, which does not, generally speaking, appear to carry any large amount of ore.

The production of lead ore in Derbyshire in 1881 amounted to 3,834 tons, equivalent to 2,875 tons of metallic lead. These ores are exceedingly poor for silver. The Mill Close Mine yielded during 1881 more than one-third of all the lead produced in the county. Four others afforded from 265 to 545 tons of lead ore each; the balance having been made up by the yield of above forty small mines. This is one of the few counties in which lead-mining does not show a serious falling off, its production for 1894 having been 5,188 tons of ore, equivalent to 3,569 tons of metallic lead.

[1] *General View of the Agriculture and Minerals of Derbyshire,* by John Farey, Sen. London, 1811, i. p. 250.

Derbyshire has yielded varying amounts of manganese ore, that at times assumed considerable importance. It occurs mostly as earthy black wad, the principal centre of production being the neighbourhood of Elton. It appears to occur as irregular bedded deposits rarely over two feet thick and not of any great extent, but apparently formed as a stratified deposit. In 1894 the output was only 36 tons.

The celebrated copper mines of Ecton[1] are situated on the borders of Staffordshire and Derbyshire. The principal deposit, which as early as the year 1778 had been worked to a depth of 200 fathoms, is a pipe vein, piercing the highly-contorted limestone beds almost vertically. There are eight main lodes coursing E. and W., and the same number of N. and S. veins, together with many smaller branches. The upper portions of the lodes contain galena, poor in silver, and blende with copper ores, the latter predominating in the lower levels. The principal ores are chalcopyrite and erubescite, and with these occur oxides and carbonates. The vein stuff is composed of very transparent calcite, which is sometimes of a bright yellow colour, colourless or bluish fluor spar frequently enclosing crystals of chalcopyrite, barytes, chalybite, iron pyrites, and calamine. The veins sometimes attain a great thickness; being in one case as much as seventy yards from side to side. From an historical point of view the Ecton Mine is interesting, as it was here that blasting was first introduced into England. Bishop Watson[2] states that he had seen the smithy in which the first borer ever used in England was made, and that the first shot fired was in the Ecton Mine. This borer must have been made for the German miners whom Prince Rupert brought over in 1636 to work the mine, and traces of whose work may still be seen in the so-called "Dutchman's" adit.

From 1760 to the end of 1768, namely, eight years, the Ecton Mine yielded 5,862 tons of copper ore worth £57,494 8*s.* 1*d.* From March 9th, 1776, to December 27th, 1817, 53,857 tons 13 cwts. of ore were raised, containing copper of the value of £677,112 14*s.* 3*d.* and yielding a net profit of £244,734 11*s.*[3] The ore appears to have generally yielded a produce of about 15 per cent. of copper.

[1] W. Pryce, *Mineralogia Cornubiensis*, 1778, p. 81. J. Mawe, *Mineralogy of Derbyshire*, 1802, p. 109.

[2] *Chemical Essays*, 1781, i. p. 332.

[3] Statement furnished by Mr. R. Taylor.

Wales.

Iron Ores.—The production of red hæmatite in South Wales is very small, since at the present time there appear to be no mines working upon this ore. Some years ago a deposit of this mineral was opened at Cwm Mountain, in Flintshire, at a short distance from the famous lead mine of Talargoch. The ore here occurs in the form of a breccia composed of angular fragments of hæmatite, cemented together by crystalline calcite stained a brick-red colour by diffused oxide of iron. This ore, which is found in irregular pockets in the Carboniferous limestone, is accompanied by brown hæmatite, which occasionally assumes the form of octahedral crystals, probably pseudomorphs after magnetite.

An oolitic variety of calcareous red hæmatite occurs in the Lower Limestone shales at Whitchurch, in Glamorganshire, but on tracing the bed for a short distance either in an easterly or westerly direction, it is found to become gradually changed into an encrinital limestone. The coal-measures of South Wales are naturally divided into two series, the upper and the lower. These are, over the whole area of the field, separated from one another by hard siliceous beds, which sometimes pass into conglomerate, and are locally known as the *Cockshute* or *White Rocks.* The hardness of these beds, together with the large amount of water which they contain, always presents formidable obstructions to sinking through them. The upper series contains but little iron ore, although the lower one, sometimes called the *Iron-bearing Measures*, comprehends numerous valuable deposits of clay ironstone. At its eastern outcrop the coal of the lower measures is bituminous, but gradually changes its character when followed in a westerly direction, until, after passing the great fault of the Vale of Neath, it becomes true anthracite. The coals of the upper series are everywhere bituminous, even when anthracite is found in the beds below. The rocks in which the coal and ironstone of this series are imbedded are known as the *Pennant Rocks.*

The lower or iron-bearing measures extend over the whole coalfield, and the principal beds of ironstone are found in the lowest strata. The ironstone is usually richest towards the eastern boundary of the field, but, although the yield of iron is less considerable, the thickness increases in going west. Near the eastern extremity of the basin, which is the great iron-producing district of South Wales, the southern outcrop dips very rapidly, while the dip of the more northern is less considerable. The highest part of the basin in which ironstone has been profitably worked is a bed of blackband occurring on the top of the Mynyddysllwyn seam of coal. This ironstone, like that which receives the same name in Scotland and North Staffordshire, contains a sufficient amount of carbonaceous matter to effect its calcination without any additional fuel. The bed, although irregular, is sometimes several feet in thickness, and occurs as a series of unconnected basins. The next ironstone bed occurs over the coal, known on the north outcrop at Dowlais as the Old Man's Coal or Gŵr-hyd Coal, while at Abercarn and Risca, on the southern outcrop, it receives the name of the Charcoal Seam and Rock Vein respectively. This is also a seam of blackband, and is worked at Abercarn under similar conditions to the Mynyddysllwyn bed; considerable quantities of this ore, which works well in the furnace, have been raised. These irregular beds are the only seams of ironstone that have been worked in the upper series.

The lower series contains so many strata of ironstone alternating with coals and shales that it would be impossible even to notice all of those which have been more or less worked; many of them are not persistent over the whole field, and consequently vary in thickness within comparatively short distances.[1] Many of the ironstones, however, exhibit a marked similarity both in structure and composition throughout a large portion of the district, and there can be little doubt that some of them exist as continuous beds. The Three-quarter Balls, which in all the eastern parts of the coal-field are traversed by numerous fissures containing quartz, calcite, spathose iron ore, millerite and hatchettine, may be quoted as an example. The ironstone measures of South Wales are exceptionally regular and well developed near Ebbw Vale, where they are extensively mined, as they are also at Blaenafon, Pontypool, Abercarn, Dowlais, &c. These ironstones in their raw state contain from twenty-one to thirty-eight per cent. of metallic iron, in addition to which traces of copper, lead, and even silver, are sometimes present. The annual production of ironstone from the coal-measures of South Wales was about 170,000 tons in 1880, but very large quantities of hæmatite and other ores are imported from Whitehaven, Lancashire, and elsewhere, for supplying the iron-works of the district.

In South Wales the lower beds of the Permian series sometimes carry some hæmatite, but such deposits are of a local character only,

[1] "The Iron Ores of Great Britain," *Mem. Geol. Survey*, part iii., South Wales.

and are usually found in basin-like hollows. One of these basins, opened some years since at Mwyndy, near Llantrissant, has yielded large quantities of ore, and had evidently been extensively worked at some long past and forgotten period, since numerous old workings, together with tools and other relics, were discovered in re-opening the mine. A similar deposit occurs at Gwar Coch, about two miles north of Porth Caul. It overlies the limestone, and sometimes contains as much as 35 per cent. of oxide of manganese, thus almost giving it the character of a manganese ore.

According to the returns of the Mining Record Office, South Wales produced no hæmatite ores in 1881, but during that year the production of brown iron ore in South Wales and Monmouthshire is stated to have been 81,372 tons. The output of iron ore has been steadily falling off in Wales, its place being more and more supplied by imported ore. In 1894 the Principality produced 11,436 tons, out of which Glamorganshire raised 11,061 tons.

CARDIGANSHIRE AND MONTGOMERYSHIRE.—The metalliferous district of Cardiganshire and Montgomeryshire consists of a tract of clay slates and gritstones, chiefly of Cambrian age, extending for a distance of about forty miles in a N.N.E. and S.S.W. direction, and varying in width from five to twenty-two miles.[1] Large areas in this district do not appear to contain mineral veins, and those which do so, and which are known to be productive, are usually characterised by some lithological peculiarity of their rocks. No rocks of igneous origin are found in any portion of this region, and the occurrence of the lodes in beds belonging to one epoch only, renders it impossible to fix their geological age with any degree of accuracy. Moreover the direction of the lodes affords no clue for the determination of their relative ages, since, however different may be their strike, no decided difference can be observed in their filling, neither is there, on the other hand, any such evidence of the passage of one through another as would allow of their being thereby classified into groups. The appearance of the outcrop of the veins of this district is usually devoid of such marked characters as would attract the attention of those accustomed to find gossans resulting from the decomposition of pyritous ores. A large preponderance of slaty matter is frequently to be observed in the lodes of this district. Its whole area consists of a succession of rolls or undulations of beds which, in the main, belong to the same series, but which vary in character

[1] W. W. Smyth, "On the Mining District of Cardiganshire and Montgomeryshire," *Mem. Geol. Survey*, ii. part ii. 1848, p. 655.

from soft shales, through many varieties of slate, flag, and argillaceous rock, to coarse gritstone and conglomerate. The zones in which the productive mines are situated lie approximately parallel to the axes of the several undulations referred to, and by imagining lines of division to run in the same direction, the veins of the district may be classified into six groups, which, although to some extent chosen arbitrarily, exhibit in many respects distinctive characters, and afford a means of consistent classification.

The first group of this district, beginning on the west, borders on the unproductive grits of Aberystwith, and includes the once celebrated mines of Tal-y-Bont, Penybontpren, Llancynfelyn, and Tre'rddol, yielding lead ores containing a very small proportion of silver, together with blende and occasionally a little copper pyrites. The lodes are usually small, and frequently intersect a fissile variety of slate, in which, throughout the whole of this district, they are rarely productive.

The second group of veins, which is of greater importance, was two centuries ago known as the "Welsh Potosi," and returned enormous wealth to the adventurers then working them. The slaty rocks here assume a paler tint, and present a peculiar silky lustre; their bedding is more massive, and the width of the veins much greater, being in some cases upwards of twenty feet. This ore is usually argentiferous, and the lead obtained from it sometimes contains as much as thirty-eight ounces of silver per ton.

The third division, ranging from Ystrad Meyric to the Devil's Bridge and along the course of the Rheidol, comprehends a number of metalliferous veins, varying in character almost as completely as do the rocks which they traverse. Thus the Llwyn Malys Lode is remarkable for the proportion of silver contained in its ores, Fron Goch for its large deposits of galena and blende, and the Estymteon Lode for its iron pyrites. The outcrops of others occasionally afford ores of manganese, while the country rock varies between gritstone, dark fissile slates, and an indurated argillaceous rock of a gray colour, in which the productive lodes of the district generally occur.

The fourth band, striking from Llampeter to the central range of Plymlumon, includes the highly argentiferous lead lode of Llanfair Clydogau, while some miles to the north are various lodes productive of common lead ores, associated with blende and calcite.

The fifth metalliferous band, ranging along the east of the Plymlumon ridge, comprehends the mines of Cwm Ystwyth, and different veins worked in the upper valleys of the Wye and Severn, as well as the more important works of Delife and the group of parallel lodes near Llanbrynmair. Beginning with the elevated mass on which the Teifi pools are situated, the southern part of this division is characterised by frequent intercalations of arenaceous matter, which, to the north, are succeeded by argillaceous shales. It is remarkable that, while throughout the former area copper pyrites is so common a constituent of the lodes as to be separately returned from several of the mines therein situated, in the latter it is but seldom found.

The sixth division, although circumscribed on the east and north by the gritty beds cropping out from beneath the Wenlock Shales, comprehends a few mines in the neighbourhood of Llanidloes, which are remarkable from the lead being accompanied by witherite and heavy spar, neither of which minerals are known to occur in any other part of the district.

In the same zone might be included another group of lead veins situated in the part of the district around Llangynnod, at a distance of nearly thirty miles from the lodes above mentioned. These last traverse slaty rocks, and the ores of lead and zinc which they afford are often associated with witherite and heavy spar. The country rocks however differ, inasmuch as beds of porphyry and of various crystalline rocks of volcanic origin are intercalated between the slates.

The most general strike of these lodes is E.N.E. and W.S.W. Although this direction is for short distances subject to frequent variations, nearly all the most important deposits agree within a few degrees with this course. The dip is most frequently towards the south, generally varying between 60° and 80° from the horizon. In some cases however the inclination is in the contrary direction, and the occasional flattening of the angle is not found in so marked a manner as in some mining districts, to cause a diminution of the productiveness of a lode.

The filling material of the vein fissures in this part of Wales is for the most part slate in angular fragments of all sizes, from the most minute particles to large masses sometimes fathoms in length and height, forming horses which split the lode into two or more distinct branches. Its most common associate is quartz, and upon the structure and colour of this, the miner, to a large extent, bases his opinion of the probable value of the lode; in doing this he makes a distinction between opaque massive quartz and the drusy cellular and sometimes granular varieties which usually accompany deposits of ore. Calcite occurs in small quantities only, and fluor spar, which elsewhere is so common an attendant of lead ores, is here entirely unknown. Galena is met with in the mines of this district crystallised either in cubes or octahedra, or in combinations of the two forms, and it is to be remarked that the argentiferous varieties are as often well crystallised as those which do not contain silver.

Cerussite is sometimes found as a product of decomposition on the outcrops of a few lodes only. Blende is frequently more plentiful than galena, but calamine has not been found in any considerable quantities excepting in the Nant-y-Creiau Mine. Copper pyrites, in irregular spots, is often mixed with the galena, and iron pyrites, which is sometimes sprinkled in the form of cubes through-

FIG. 76.—Estymteon Lode; section.

out the slate rock, is found abundantly in the lodes of this district. Chalybite is met with in the form of branches in the vicinity of some of the veins, and an ore of manganese has been obtained from old workings on the Drosgol hill, near Rheidol; it is, however, an impure hydrous oxide of but little commercial value.

The various minerals filling the veins of these counties are rarely disposed with such regularity as to lead to the conclusion that the deposition of one substance had ceased before that of another had commenced; they usually occur in strings and spots which are sometimes parallel for short distances, but they more frequently ramify in an irregular manner, and often form a network of branches. Generally, however, it may be observed that the calcite takes the inner side of the quartz, whether occurring in drusy cavities or in ribs, and galena appears to occupy an analogous position with regard to blende. A structure of this kind, varying constantly in its details, exhibited by the Estymteon lode, is represented in Fig. 76, in which *a* is copper pyrites, *b* quartz, *c* blende, *d* iron pyrites, and *e* galena.

When a deposit is of considerable thickness the metalliferous portion of it frequently exhibits a tendency to form in bands, and wherever one of these becomes wedged out, another, and nearly parallel stripe, commences, forming a *splice*, as shown in Fig. 77, in which *a* and *b* represent two separate and nearly parallel masses of ore which form a splice with overlapping ends. As before mentioned, the structure of the veinstones of this part of Wales is frequently brecciated, angular fragments of slate being united by a cement consisting either of quartz, galena, or blende, while more rarely, a ground-mass of calcite encloses angular pieces of galena, chalcopyrite, or blende.

Cross-courses, generally filled with clay, but sometimes appearing as mere partings in the rock, are not unfrequent, and occasionally heave the lodes for a distance of several feet; they are, however, less common than in many other mining districts. The country rocks on the opposite sides of many of the lodes have been affected by unequal movements resulting in the displacement of one or both of the walls; but, from the absence of easily

FIG. 77.—Vein forming a splice

recognised beds, it becomes difficult to measure any change of level which may have taken place.

Numerous facts have been observed with regard to the ore-bearing portions of these lodes which are in perfect accordance with the experiences of other districts. Thus when two lodes approach one another under a small angle, their junction is usually marked by an expansion of the deposit of ore, and a similar effect is produced when branches or short veins fall into the principal lode; the effect being the same whether this falling together of the branches takes place along the line of strike or on that of the dip. The same result is observed in a greater degree where two or more lodes become united into one. The productive portions of the lodes are generally more continuous in their vertical than in their horizontal range, and they have most frequently an inclination towards the west. From this circumstance it might be inferred that they run parallel to the bedding of the more metalliferous rocks, but Sir Warington Smyth is inclined to believe that they more frequently conform to the planes of cleavage of the country rock than to those of its bedding. The lead veins of this part of Wales differ materially from those of Cornwall in one important point, namely, that whenever they pass from a harder to a softer rock their mineral contents decrease in quantity.

In the year 1881, the most important operations carried on in Cardiganshire were those of the Lisburne Mines, which produced during that year, 1,005 tons of lead ore, and 3,550 oz. of silver. The most productive mine of Montgomeryshire during the same period was the Van, yielding 2,600 tons of lead ore, 1,400 tons of blende, and 23,400 oz. of silver.

In common with nearly every other British lead-mining district, these counties show a marked falling off in recent times. Their production for 1894 was as follows :—

	Lead ore. Tons.	Lead. Tons.	Silver. Oz.	Zinc ore. Tons.
Cardiganshire	323	223	63 (?)	3,033
Montgomeryshire . . .	502	396	3,922	—

Nearly all the zinc ore was produced by one mine, Fron Goch at Devil's Bridge, which raised 2,645 tons. This mine was also the principal lead producer in its county, the Van mine being practically the only one in Montgomeryshire.

MERIONETHSHIRE.—This county comprehends no extensive or largely productive metalliferous areas, but is remarkable, inasmuch as some of its rocks enclose veins which have been long known to be auriferous. The gold-bearing district would appear to be mainly confined to about twenty-five square miles of the county lying on the north of the turnpike road leading from Dolgelly to Barmouth. In this district the Cambrian rocks are overlain by others of Silurian age, and about half way between the two places, a stream which descends from the higher range of Llawllech discharges its waters into the Mawddach river below Pontddu. On either side of this rivulet rises a mountain, one being the Vigra and the other the Clogau, in both of which copper mines have been worked intermittently for many years. Among the mines which at one period attracted the greatest amount of attention are the Vigra and Clogau, the Dol-y-frwynog the Cefn Coch, and the Prince of Wales.

So long ago as the year 1844, a paper was read before the British Association by Mr. Arthur Dean, who stated that a complete system of auriferous veins existed throughout the whole Snowdonian region of North Wales. In consequence of this and of equally sanguine statements made by others, mining operations were shortly afterwards commenced at Cwm Eisen, but the results obtained being unsatisfactory, the mine was abandoned. About two years subsequently to this, machinery for crushing and amalgamation was erected at Dol-y-frwynog, but the treatment of several hundred tons of veinstone having resulted in the production of only a small amount of gold, the operations were suspended.

Among the auriferous veins which have from time to time been worked in North Wales, that opened in the Clogau Mine has been in operation for the longest time and has produced a considerable amount of gold. At Clogau the workings have been exclusively conducted upon the St. David's or Gold Lode, which is situated nearly a mile further north than that formerly worked for copper. At a short distance north of the St. David's Lode, the massive greenish grits of the Cambrian system emerge from beneath highly inclined beds of Lower Silurian age. The vein, which courses nearly E. and W., is often from two and a half to nine feet in width, and commonly lies between two distinct walls, especially on the southern side; it is usually almost perpendicular, but sometimes dips slightly towards the north.

It is chiefly composed of quartz and calcite, the latter mineral sometimes forming masses of several feet in width; where the calcite assumes the appearance of a friable and granular marble, it not unfrequently contains gold, but when, on the contrary, it becomes foliated or is coarsely granular, that metal appears to be entirely wanting. Spots of iron pyrites and chalcopyrite are frequently scattered through the veinstone, which circumstance caused the vein to be originally regarded as a copper lode. Fragments of the country rock are often included in the vein, and a few yellowish metallic points and crystalline spangles and plates of gold are sometimes disseminated in the lode. With the gold is not unfrequently associated the compound of tellurium, bismuth and sulphur, known as tetradymite, which occurs in crystalline scales of silvery whiteness and of brilliant metallic lustre.[1] The laminæ of the country rock on either side of the lode strike only a few degrees more to the N. of E. than the lode itself, and they are consequently intersected at so small an angle that in places where the lode is somewhat obscure it occasionally requires care on the part of the miner to prevent turning off into the country rock. Another noticeable feature of this vein is the frequent occurrence of nearly horizontal planes of division crossing it from one side to the other. In width the St. David's Lode is

[1] W. W. Smyth, "Gold Mining at Clogau, North Wales," *Mining and Smelting Magazine*, i. 1861, p. 359.

even more than usually variable, for although, as before stated, it is sometimes nine feet in width, at others it is reduced to a mere fissure.

The experience acquired from the working of this and other gold veins in North Wales goes to show that the only remunerative material is that small proportion of the lode which contains visible gold, and that this is not usually present in sufficient quantities to pay the expenses of mining, &c.; several rich bunches of gold quartz have, however, been found in the St. David's Lode, and for a short time the Vigra and Clogau Mines were, on a comparatively small scale, very profitable.

The total weight of gold, of an average value of £3 4*s.* per oz. obtained in North Wales from the end of 1844 to April, 1866, is estimated as follows:—

	Oz.
Old Dol-y-frwynog	117
Prince of Wales	63
Cwm Eisen	176
Gwyn-frwynog	6
Cefn Coch	478
Castell Carn Dochan	182
Vigra and Clogau	11,778
	12,800

Only a very small quantity of gold was obtained from the Welsh mines during the twenty years following 1866. Mining operations were, however, for some years carried on at Clogau with the view of reaching the St. David's Lode at a greater depth than any at which it had been hitherto worked. Shortly after the intersection, in 1881, of the lode by this deep cross-cut, it was understood that about 225 oz. of gold had been obtained from a level driven upon its course, but no announcement of any further discovery was made.

In fact, Welsh gold mining remained practically neglected until 1888. In the previous year a lot of rich specimen ore was taken out of a reef about eight miles north-west of Dolgelly, and the Morgan Gold Mining Company was floated in London on the strength of these finds; after a chequered career the Company had to suspend operations, but the mine was refloated as the British Gold Mining Company and seems now (1895) to be doing well. It is worth noting that work can be carried on here under very economical conditions, ample water power being available for driving all the machinery. The reef which seems in places to split into a number of branches runs about east and west, and has a steep dip of about 80° to the north. The footwall consists of gray, the hanging of blue slates, whilst a porphyritic dyke appears to traverse these rocks not very far from the hanging wall of the reef. The strike of the slates seems to be parallel or nearly so to that of the reef, but their rather obscure dip seems to be in the opposite direction. The width of the lode varies from four feet to twenty or more, and encloses numerous horses of slate; it consists of very white quartz, much mineralised in places, chiefly with iron pyrites, arsenical pyrites, zinc blende, galena, and copper pyrites. The bulk of the reef is low grade, say about five dwts. of gold to the ton, and shows but little visible gold; from time to time patches or shoots of rich ore are met with, showing much free gold and yielding numerous fine specimens; one of the largest of these shoots was traced for a length of over 300 feet. It would seem that the mass of the reef, if worked on a large scale, ought to about pay expenses, and that any rich pockets or shoots that may be cut, should yield a profit. In 1894 this mine produced 5,083 tons of ore yielding 3,063½ ounces of gold, valued at just over £10,000. The total production of this district for the same year was as follows:—

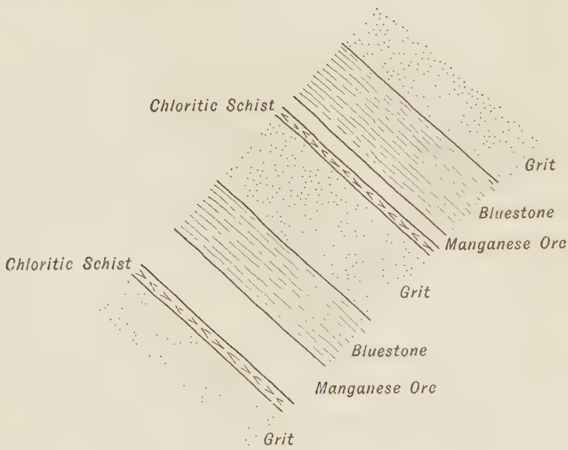
Ore	6,603 tons.	
Gold obtainable	4,235 ,,	(worth £14,811).
Value at mine	£13,573	

The annexed table shows the production of the district since the recent revival in gold mining:—

	Ore. Tons.	Gold. Oz.	Estimated value at Mine. £
1888	3,844	8,745	27,300
1889	6,226	3,890	10,746
1890	575	206	434
1891	14,117	4,008	12,200
1892	9,990	2,835	9,168
1893	4,489	2,309	7,657
1894	6,603	4,235	13,573

In the Mawddach valley, a little below Tyn-y-groes, but on the other side of the river, is the Glasdir Copper Mine, where the ore instead of being contained in a lode, is disseminated in a bed of altered slaty rock. The iron pyrites and chalcopyrite which here occur are found in the vicinity of the branches of an eruptive felspathic rock which has broken through the slate in all directions. When prepared for market this ore yields only a small percentage of copper, but contains a little silver, and from one to one and a half ounces of gold per ton. The annual returns from this mine were very inconsiderable.

Beds of carbonate of manganese with some silicate, the outcrops of which have been to some extent changed into black oxide, occur intercalated between sandstones, grits and conglomerates of the Cambrian formation, and have been mined to some extent. The beds vary from one to two feet in thickness, and yield ore, averaging about twenty-seven per cent. of metal, which is used in spiegel making. These deposits are evidently symphytic and belong to group *b* of that class. Fig. 78 taken from a paper by E. Halse,[1] shows the mode of occurrence of these deposits; the



Scale 1 inch = 6 feet.

Fig. 78.—Section of Merionethshire Manganese Deposit.

section is taken at a point where two beds of manganese are found, but this is by no means usual and may be looked upon as the exception. One mine, Rhinog, at Llanbedr yielded over 1,000 tons in 1894, and the output of the entire country was 1,683 tons. Though not a large production and though the ore is far poorer than that wrought in other parts, it forms the leading factor in British manganese mining, the total production of Great Britain for the same year having been only 1,809 tons, the imports of ore into this country being just about seven times as much as the production, which has entirely changed its complexion and has fallen off until these bedded deposits are almost the only

[1] "Manganese in Merionethshire." *Trans. N.E. Inst. Min. Eng.*, xxxvi. 1886, p. 103.

manganese mines worked in the kingdom. These deposits were first worked about the year 1885, the total production of Merionethshire having been as follows:—

1886	11,286	tons.
1887	12,391	,,
1888	4,006	,,
1889	8,671	,,
1890	12,018	,,
1891	8,990	,,
1892	5,119	,,
1893	635	,,
1894	1,683	,,

FLINTSHIRE AND DENBIGHSHIRE.—In this mining area a long series of parallel veins course across the Mountain Limestone into the Millstone Grit, and are, further east, only observable as faults in the coal-measures. These veins are intersected by a system of strongly marked cross-courses, which are traceable for many miles in length. They are usually barren, but exceptionally, as in the neighbourhood of Holywell, they have afforded large quantities of lead ore. In former times almost fabulous amounts of lead were obtained from these mines, the galena having been frequently found in a state of purity and solidity not often equalled elsewhere. When unproductive, these veins are usually filled either with opaque calcite or with plastic clay, and the operations of the miner are often impeded by an unusually large influx of water. The most remarkable mines of this district have been Talargoch, near Rhyl, and Minera, six miles north-west of Wrexham.

Many of the lead mines in this district, and particularly some of those in the neighbourhood of Mold, have been remarkable for the large quantities of white lead ore, cerussite, which they have yielded when the veins intersect the sandstones of the Millstone Grit. Large quantities of this ore have also been obtained from pipe veins which had possibly been cavities produced by the action of water, and subsequently filled with various mineral substances brought into them in a state of solution, or else may have been formed by metasomatic action.

Minera, which was some years ago the most productive lead mine in Great Britain, occupies a considerable portion of a patch of Mountain Limestone which has been disrupted by faults from the southern extremity of the mining area of Flintshire. On the northern side there is a downward displacement, while on the southern there is a throw towards the east. The sett comprehends portions of the coal-measures and of the Millstone Grit together with certain underlying Silurian rocks.

The Mountain Limestone of this district rests unconformably upon Lower Silurian strata, but somewhat further south, thin sandstones and slates of Devonian age are interposed between the limestone and Upper Silurian shales. The Carboniferous limestone is here usually overlain by Millstone Grit varying in thickness from 30 to 200 feet, and this is occasionally covered by true coal-measures; while in some places the Millstone Grit is entirely absent and the coal-measures rest immediately on the limestone. These different strata are frequently much disturbed, and afford examples of almost every description of mineral vein varying from true lodes to thin branches and strings of ore, generally destitute of veinstone.[1]

Two principal lodes are worked in this mine, namely, the Old Vein and the North or Red Vein. The Old Vein has been formed in a fissure presenting all the characteristics of a fault, with a downthrow to the N.E. Its course is nearly S.E. and N.W., with a dip of about 80° from the horizon towards the N.E.; this vein at times swells out into large masses of ore and gangue, the latter chiefly consisting of calcite and pulverulent quartz; it then again decreases in size and becomes nipped or otherwise impoverished. In some places it attains a thickness of fifteen yards, while five yards is by no means an uncommon width; and in such cases two nearly parallel levels were sometimes driven at the same horizon in the vicinity of its walls.

Towards the west the veins undergo a change, becoming, themselves, less productive, but apparently acting as feeders to various irregular pipes and floors of lead ore. Under these conditions some exceedingly rich deposits of ore have been met with, and the enormous cavern-like excavations found in various parts of the older workings sufficiently attest the truth of statements which have been handed down respecting the large amounts of ore which were obtained from them. In this part of the mine the country rock is a compact white limestone, and the ore deposits are unaccompanied by veinstone of any kind. The vein fissures are often very open, and show evidence of the action of carbonic acid upon the limestone. These openings form channels for the passage of immense quantities of water, carrying with it, in rainy seasons, a considerable amount of clay and sand.

[1] George Darlington, "Mineral and Geological Sketch of the Minera Mining Field," *Mining and Smelting Magazine*, ii. 1862, p. 207.

Near the eastern extremity of the workings, this vein, in the upper levels, occurs in slates and shales belonging to the coal-measures and Millstone Grit, and is usually very poor. At a greater depth it intersects the Carboniferous limestone and becomes to some extent productive for lead ore, but instead of being filled with galena, the vein is, to a large extent, made up of brown blende, which is frequently well crystallised. This ore is mixed with pulverulent and massive quartz, and contains disseminated masses of galena.

The North Vein, like the Old Vein, to which it is nearly parallel, has been formed on a line of fault, and has a down-throw to the N.E., but apparently to not quite so great an extent; its throw however increases towards the east. The deposits of ore in this vein have often been exceedingly pure and massive, frequently containing not more than 15 per cent. of impurity as drawn from the mine. The character of the ore and its associated minerals differs in some respects from those of the Old Vein in the same ground. The ore is steely and fine-grained, with very little admixture of large-grained cubical galena, but although fine-grained, it seldom contains above four ounces of silver per ton. Blende is almost the only associated mineral. The walls of this vein are very imperfectly defined and sometimes can scarcely be said to exist.

In 1864 the Minera Mines produced lead ore and blende of the value of £103,293; of late years, however, the yield of lead ore has fallen off considerably, although a larger amount of blende has been annually raised. In 1881 these mines produced 1,394 tons of lead ore, 5,468 tons of blende, and 6,970 oz. of silver; their greatest depth in that year was 158 fathoms. In 1894 they produced 682 tons of lead ore and 5,715 tons of blende, the yield of silver being 2,246 ounces.

In 1881 the production of lead ore in Flintshire was 4,392 tons, equivalent to 3,297 tons of metallic lead, and 29,000 oz. of silver.

During the same year the mines of Denbighshire yielded 1,587 tons of lead ore, or 1,193 tons of lead, and 7,055 oz. of silver.

In 1894 these counties produced respectively ores as shown below:—

	Flintshire.	Denbighshire.
Zinc ore	1,181 tons	5,732 tons
Value	£3,095	£25,318
Lead ore	5,435 tons	784 tons
Lead obtained	4,274 tons	600 tons
Silver	36,221 oz.	2,613 oz.
Value of lead ore	£34,181	£4,858

ANGLESEA.—Parys Mountain is situated about two miles inland from the northern coast of the Island of Anglesea, its barrenness contrasting conspicuously with the fertile pasture lands of the surrounding country. Its height above the sea does not exceed 500 feet, but although the larger portion of its surface is covered with sufficient soil to support ordinary vegetation, it nevertheless scarcely produces either a blade of grass or a bunch of heather. This mountain, which was at one time widely celebrated for the very large amount of copper annually obtained from its southern slope, was in modern times first systematically explored in the year 1768. Since that period, like all similar enterprises, its mines have been subject to numerous fluctuations, but they have, notwithstanding, remained constantly in operation. They lie somewhat less than two miles south of the town of Amlwch, and are enclosed in a band of Silurian slate, which stretches in a southwesterly direction almost across the island. At Parys Mountain

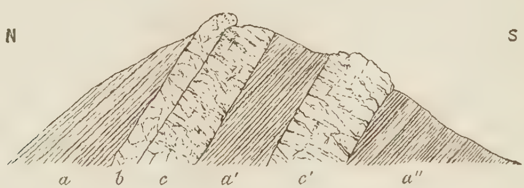


FIG. 79.—Parys Mountain; transverse section.

these slates are intercalated with bands of felspathic rocks of presumably eruptive origin, but which do not appear to have ever been carefully examined. The sketch section, Fig. 79, will serve to explain the order of sequence of the various rocks.[1]

The northern slope of the mountain consists of slate, *a*, in which occur small irregular branches of quartzose and felspathic rock, together with occasional bands of a greenish trap. This is followed by a very powerful quartz vein, *b*, which traverses the hill from one side to the other, and is known as the Carreg-y-doll Lode. To this succeeds a thick band of felstone, *c*, which varies considerably both in colour and in texture. A band of deep blue slate, *a′*, follows this on the south, and is itself succeeded by another band of felspathic rock, *c′*, very similar to the last, beneath which is the slate, *a″*. As shown in horizontal section, Fig. 80, the rock-mass is traversed nearly

[1] T. F. Evans, "The Mines of the Parys Mountain," *Trans. Manchester Geol. Soc.*, xiv, 1878, p. 357.

at right angles to the strata by two distinct faults, known respectively as the Great Cross-course and the Carreg-y-doll Cross-course. The former is of considerable width, varying from 20 to 60 feet, filled with broken and crushed fragments of the neighbouring rocks, and interfering considerably with the continuity of the strata. The latter, on the contrary, is a mere transverse cleft which has but little effect on the relative positions of the rocks forming its sides.

The central dislocated block of the felspathic rock, *c*, lying between the two cross-courses exhibits evidences of decomposition and disintegration which are not met with in other portions of its course, and it, in many places, consists of a soft concretionary mass

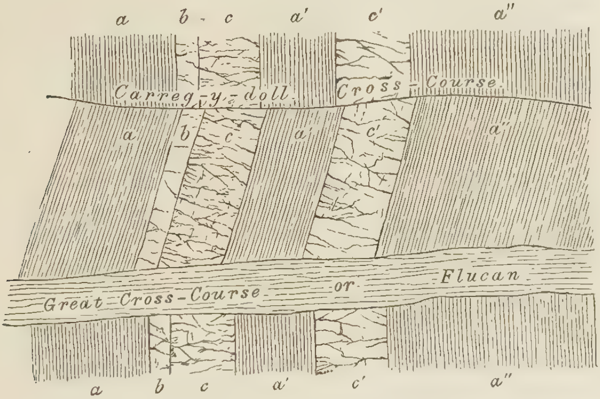


Fig. 80.—Parys Mountain; horizontal section.

containing so many shell-like nodules, that the miners have given it the name of *Carreg-y-Grogan*, or shell-stone. In these, kernels of copper pyrites occur in such large quantities that this ground has formed one of the most profitable resources of the mines.

In addition to the foregoing, and beginning at the north in the band *a*, a large deposit of copper pyrites associated with quartz, &c., known as the North Discovery Lode, extended for a few fathoms west of the Great Cross-course for a distance of 90 fathoms westward. This more nearly resembled an ordinary lode than any other which has been discovered in the mines. It was well defined and was enclosed in a country rock of hard slate, dipped at an angle of 60°, and the shoot of ore which it carried inclined westward at the rate of three feet in a fathom. It was also distinguished from all other similar deposits by the almost complete absence of felspathic rocks. This great deposit has now been completely worked away, after having yielded, in the aggregate, copper ores of the value of about a million pounds sterling.

With the exception of some small quartzose strings, sometimes containing a little copper pyrites with blende and galena of no commercial value, no ore occurs between this and the Carreg-y-doll Lode. This is an immense sheet of quartz, *b*, varying from five to sixty feet in thickness, and sometimes containing valuable bunches of copper pyrites; iron pyrites is also present, but not in such large quantities as in the rocks lying to the south. This lode contains druses or vughs of extraordinary dimensions, one of them, cut into some years ago, which was beautifully lined with crystals, being no less than eight fathoms in length and four in height. The bunches of ore in this lode, like those before described, exhibit a tendency to dip towards the west.

The large felspathic band *c* also encloses considerable deposits of copper pyrites, which occur in the form of strings and bunches. This ground has yielded large profits, and a considerable amount of copper is still disseminated through the rock, but it is too sparsely scattered to repay the expense of mining and concentration.

Extensive as these deposits may be, they are much less important than are those which occur to the south of the felspathic band, and which lie immediately between it and the band of slate marked *a′*. At the junction of these two rocks the mountain has been almost divided into two parts by two large open-cast excavations varying in depth from 110 to 140 feet, and occupying an area of somewhat more than twelve acres in extent. These are bounded on the north by the band of felspathic rock marked *c*, and on the south by the stratum of slate *a′*. It is here that occurred the great body of copper ore which once exercised a considerable influence upon the European copper market. The ores did not, on an average, contain more than 5 to 6 per cent. of copper, but for a time there was scarcely any limit to their possible production, and the proprietors, to a large extent, commanded the market.

The metalliferous mass worked in these open cuttings is composed of three distinct members, namely:—

1st. A bed of iron pyrites.

2nd. A bed of copper pyrites.

3rd. A thick bed of an ore locally known as *bluestone*, which sometimes lies beneath the deposit of copper pyrites.

This ore varies somewhat in composition, but the following analysis, made by Mr. F. Claudet, may be taken as approximately representing its average composition :—

Lead	14·46
Copper	2·13
Zinc	27·89
Iron	11·45
Sulphur	29·05
Siliceous rock	14·47
	99·45
Silver	6 oz. 15 dwt. per ton.
Gold	traces.

The iron pyrites and chalcopyrite invariably occur associated with quartz and felspathic rock, but the bluestone is usually nearly pure, containing only branches and nodules of white quartz. The stratum of this mineral, which underlies the other two beds of ore, is by no means regular, having sometimes a thickness of from 50 to 60 feet, while at others it is reduced to a few inches or entirely disappears. It occurs in its purest state when intermixed, in the form of elongated lenticular masses, with the enclosing slate. Large quantities of this ore might be raised if a satisfactory market could be obtained, but, although much attention has been bestowed on its metallurgical treatment, none of the processes hitherto tried appear to possess the necessary simplicity, and the demand is consequently somewhat limited. The beds of pyrites and bluestone appear to thin out in descending, while that of copper ore would seem rather to improve in depth.

The water from these mines contains a considerable amount of the sulphates of iron and copper. This water is first raised to the surface by wooden pumps, and then stored in reservoirs prepared for its reception. In these it deposits all the sand and clay it may hold in suspension, and when it has become perfectly clear, it is tapped off into the precipitators as may be required. Into these scrap iron is introduced and the copper thrown down in the usual way. After the precipitation of the copper, the water, which has been treated by metallic iron, is allowed to flow into large basins several acres in extent, where by a natural process of oxidation, it deposits highly basic salts of iron, which are largely used for the purification of coal gas and for the manufacture of various iron-oxide paints. Of this *ochre* the Anglesea mines sold, in 1881, 3,011 tons, together with 2,305 tons of bluestone, and 768 tons of copper in the form of ores and precipitate. In 1894 they produced: Bluestone, 955 tons, valued at £1,434, and estimated to yield 212 tons of zinc, 127 tons of lead, and 9,518 oz. of silver; ochre, 1,175 tons, valued at £2,280; copper precipitate, 230 tons, valued t £2,140; so that the output is now clearly a diminishing one.

Isle of Man.

Underlying the Silurian and Carboniferous rocks, which are well represented in the Isle of Man, and breaking through them in various places, are granite and other igneous rocks. The granite is found at the surface in two localities, one in the north of the island between Laxey and Ramsey, and the other in the centre on the eastern side of South Barrule. In addition to these granitic outbursts, dykes of porphyry and diabase exhibit traces of volcanic action in all parts of the island. Everywhere the adjacent strata are greatly altered by contact with the granite or other igneous rock, and metalliferous minerals occur abundantly near the line of contact.

The two principal mines, Foxdale and Laxey, are situated near the great outburst of granite, Laxey being near the northern and Foxdale near the southern mass. Resting on the granite is a series of slaty rocks, which occupy more than two-thirds of the entire area of the island. Valuable metalliferous veins traverse these slates, and for many years mines have been worked with great success both at Foxdale and Laxey, and, less profitably, in several other parts of the island.

At Laxey the direction of the main lodes is about 8° E. of N., with an easterly underlie of two feet in a fathom. At Foxdale the principal lodes course 8° S. of E., with a southerly underlie also of two feet per fathom. The main lode has been worked, but not quite continuously, for about four miles on its east and west course, and in this distance is intersected by several counter veins, and by at least three north and south veins, all of which have a dip towards the west. The Laxey Mines are worked exclusively in Lower Silurian slate, but in the Foxdale Mines the deeper workings are entirely in granite, which was reached after first passing through the slate into a layer of granite thirty feet in thickness, and then again sinking through a band of slate. A new perpendicular shaft has been sunk to intersect the lode at a depth of 250 fathoms.

Foxdale is remarkable for the great size of its main lode, which occasionally expands to a width of forty feet. To the mineralogist

Foxdale is extremely interesting. In the large cavities or *lochs* in the lode, magnificent crystals of iridescent galena are often found. The galena has occasionally a very high percentage of silver. Argentiferous tetrahedrite is frequently to be met with, as also are splendid pseudomorphs of iron carbonate after fluor spar, resembling those formerly found at the Virtuous Lady Mine near Tavistock. Recently plumosite, the *Federerz* of the Harz miners, has been discovered.

Of late years, a remarkable feature has been the presence of large quantities of carbonic acid gas, given off from crevices in the south wall of the lode. At the present time (1883) in the eastern end of the 185-fathom level, the amount of gas is so large that, although volumes of compressed air are continually being poured in from two air-pipes, the men experience the greatest difficulty in working; and, as candles will not burn, the value of the end can only be determined by the ore brought out. The yield of the Foxdale mines during the year 1881 was 3,419 tons of lead ore containing 69,080 oz. of silver.

In 1881, the deepest portion of the Laxey Mines was 259 fathoms below the adit. In that year they yielded 1,700 tons of lead ore containing 5,250 oz. of silver, and 7,567 tons of blende. The other mines in the Isle of Man returning lead ore were Ballacorkish, where fine specimens of the carbonates and phosphates of lead occur, East Foxdale, Kirk Michael, and North Laxey.

Evidences of mining operations for copper, carried on at a very early date, have been observed at Bradda Head. This lode, at the S.W. corner of the island, is one of the finest surface exhibitions of a mineral vein to be seen in Europe.[1]

Several attempts have been made, with more or less success, to work the hæmatite lodes which are found at Maughold Head, near Ramsey.

According to the statistics of the Mining Record Office, the total returns in 1881 from mines in the Isle of Man amounted to 5,675 tons of argentiferous lead ore of the value of £76,513, and 7,567 tons of blende worth £28,701; with 120 tons of hæmatite worth £60, and 60 tons of copper ore worth £90; making the total value of metalliferous minerals produced in the island £105,364. In 1894 the output was as follows:—

Zinc ore	2,579 tons, value	£8,582
Lead ore	5,624 ,, ,, ...	£42,218

[1] W. W. Smyth, "Metallic Mining," *Stanford's British Manufacturing Industries*, i. 1876, p. 15.

The quantities of lead and silver obtainable from the last named were 4,134 tons and 111,325 oz. respectively; of the total blende production, 2,040 tons came from the Great Laxey Mine, whilst the bulk of the lead, or 4,800 tons, was produced by Foxdale.

Ireland.

Mines are by no means numerous in Ireland, for, although ores of various metals are not of unfrequent occurrence, there would appear to be but few localities in which they occur in sufficient abundance to render their extraction remunerative.

Wicklow.—The county of Wicklow is composed of slaty rocks chiefly of Lower Silurian age, which are broken through by masses of granite and intersected by dykes of porphyry and greenstone. In the neighbourhood of the granite the clay slates are often converted into mica schists, granulite, or quartzite, and the metalliferous deposits of the district are, for the most part, comprehended within a somewhat narrow belt extending for some distance on either side of the junction of the granite and schists. They may be divided into three principal groups, namely :—

1.—Deposits of copper ores and of cupriferous iron pyrites chiefly in Silurian slates.

2.—Lead ores in granite.

3.—Gold in the sands and gravels of various streams near the base of Croghan-Kinshella.

There are several copper mines in the county of Wicklow, some of which are said to have been wrought from very ancient times. Up to the year 1839 those of the Ovoca district were worked exclusively for copper, excepting that a certain amount of lead ore was raised at Cronebane and Connary. About the time above referred to, a sudden demand for pyrites sprang up in this country in consequence of the suspension of the sulphur trade with Sicily, and for many years these mines were worked principally for iron pyrites. At the present time Irish pyrites has been almost entirely superseded in the manufacture of sulphuric acid by that imported from Spain and Portugal, in consequence of which the mines of Wicklow, although once yielding 60,000 tons of pyrites annually, are now no longer actively worked. The output from Ovoca was only 3,828 tons of pyrites valued at £2,264 in 1894. It was formerly supposed that the ores occurred in deposits having the same strike and dip as the enclosing rocks, but more recent investigations have conclusively shown that, although in their general direction they approximate more or less closely with the general strike of the country, they nevertheless invariably cross the strata, although often at a very small angle. In depth the lodes always underlie faster than the enclosing rocks.[1]

The country consists principally of slates and schists, all of which are more or less metamorphosed, and associated with them are various pyroxenic and felspathic rocks. The former are generally regarded as being of eruptive origin, but the felspathic rocks exhibit somewhat remarkable peculiarities. At one time they were supposed to run parallel with the channel of mineral ground enclosing the lodes, but it has been pointed out by Sir W. W. Smyth that in some places they run across it; and Mr. Kinahan has shown that they sometimes occur in isolated masses, and that, although some of them are intrusive rocks, the majority may be regarded as being of metamorphic origin.

The lodes upon which mining operations have been conducted east of the Ovoca River are principally in clay slate, and occupy a belt extending from the Ovoca for about six miles in a north-easterly direction. The principal lodes are not, however, continuous throughout this distance, but are much interrupted by faults, and sometimes become either greatly reduced in width, or appear to die out altogether; patches of dead ground sometimes intervene, in which no regular veins have been discovered.

In West Cronebane there is, on an average, a depth of six fathoms of drift over the back of the lode, and under this there is a breccia composed of angular fragments of country rock cemented together by hydrated oxide of iron. This latter rests upon the gossan, which here consists of limonite, nearly the whole of which was removed some years since, at a time when iron ores were in exceptionally great demand. In a westerly direction the breccia and gossan gradually thin out, until upon Tigroney brow both have been removed by denudation, and the unaltered pyrites makes its appearance on the surface. In West Cronebane the gossan in some places rests upon a ferruginous clay, and at one point carbon is present in the form of a graphitic shale. Occasionally the gossan is found to rest on clay containing patches and strings of melaconite and fahlerz, with occasional veins of pyrites composed of detached sand-like crystals, which in depth become consolidated and lose

[1] P. H. Argall, "Notes on the Ancient and Recent Mining Operations in the East Ovoca District," *Proc. Roy. Dublin Soc.* ii. 1880, p. 211.

their granular character. In proportion as the thin branches of pyrites proceed downwards they increase both in width and number, thus gradually replacing the laminæ of the enclosing killas until, eventually, the entire width of the lode is composed of pyrites. Still further down the iron pyrites becomes more dense, but is frequently interlaminated with bands of hard killas, and under these circumstances the hardest ribs not unfrequently contain two per cent. of copper.

At Tigroney and West Cronebane the country rock, for a considerable distance both north and south of the great pyrites vein, is mineralised by finely disseminated particles of iron and copper pyrites, and these minerals, having become oxidised near the surface, impart a reddish-brown colour to the partially decomposed rocks. In these mineralised rocks, for a distance of 25 fathoms south of the main lode, are lenticular deposits of yellow copper ore. As first pointed out by Mr. Weaver, these rocks are traversed by horizontal joints, of which the extent is unknown, but which are sometimes two inches in width, while at others it would be difficult to insert the blade of a knife. These joints usually occur at intervals in depth of about five fathoms, and are crossed nearly at right angles by a system of almost perpendicular joints, by which the country is divided into huge nearly rectangular masses. None of the copper deposits are accompanied by any gossan; but when one of these joints comes into the immediate vicinity of a deposit of copper ore, it becomes partially filled with small fragments of country rock, cemented into a breccia by hydrated ferric oxide and stained by various compounds of copper.

These deposits of yellow copper ore are generally lenticular masses intercalated between the laminæ of the strata, gradually thinning off to nothing both in length and depth. In some cases two or more of such deposits are connected together by branches or strings. Associated with these deposits are counter lodes, many of which occupy the perpendicular joints before referred to; and when these come in contact with lenticular deposits they form junctions with them, and they themselves for a certain distance contain copper ores of above the average produce. Lenticular masses of cupriferous pyrites are sometimes intercalated with the ordinary iron pyrites of the great lode.

The mode of occurrence of the iron pyrites and chalcopyrite at Tigroney and West Cronebane will be understood by referring to Fig. 81, in which *a* represents the main lode, displaced by various faults, and *b* lenticular deposits of yellow copper ore on its south wall. Fig. 82 is a transverse section on the line *d e*, in which the lenticules of yellow copper ore, shown south of the lode, are not indicated by a letter. At the surface the lode was at this point eight fathoms in width, decreasing to six fathoms at the 77-fathom level, below which it was suddenly cut off by a slide underlying 45°

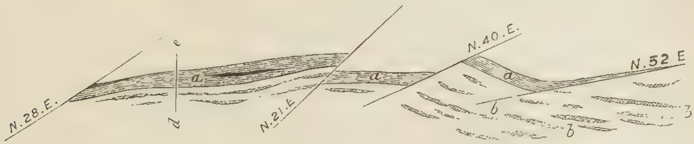


FIG. 81.—Tigroney and West Cronebane; horizontal section.

south. This slide was sunk upon for a distance of thirteen fathoms, where a vein of cupriferous pyrites was found two feet in width, the walls of which were opening out in depth. The vein has not been proved below the 90-fathom level, which is the deepest point reached in any of the eastern Ovoca mines. The great sulphur lode in West Cronebane is cut off towards the east by dead ground, and is not again met with in a workable form until East Cronebane is reached, a distance of 300 fathoms. This lode in East Cronebane and Connary is wedge-shaped, and becomes gradually smaller as the depth increases. At one or two points it has been followed down almost to the point of a wedge, but it is

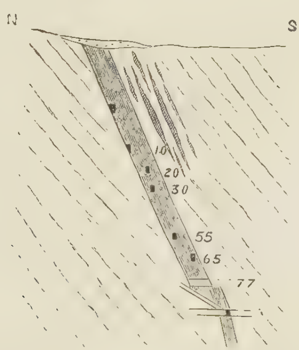


FIG. 82.—Tigroney; transverse section on *d e*.

not impossible that further exploration might lead to the discovery of a splice, and that the lode may thus continue in depth.

South of the Connary main lode is Wall's Lode, with a similar bearing and underlie, which for a short distance yields iron pyrites with a little chalcopyrite. Towards the east it breaks up into a number of strings, while westward it is cut off by a mass of felspathic rock. Further north-east is another deposit of metallic sulphides known as the Kilmacoo Lode, which is chiefly made up of clay and soft ground, containing bunches and veins of a bluestone having nearly the same composition as that found at Parys Mountain in Anglesea. This bluestone, which is sometimes called *kilmacooite*, yields from six to eight ounces of silver per ton of ore, together with traces of gold. The copper ores from the Wicklow mines contain from 8 to 12 per cent. of copper, while the iron pyrites affords from 33 to 36 per cent. of sulphur. About one-sixth of the iron pyrites is to some extent cupriferous, containing from 1 to 2 per cent. of copper, and about 38 per cent. of sulphur. Nearly all the pyrites from these mines contains minute quantities of gold, silver, nickel and cobalt. A certain amount of copper is annually obtained from the mine waters by precipitation with metallic iron. In 1880 the total annual yield of copper from the Wicklow mines, including that obtained in the form of precipitate, did not amount to 100 tons, whilst since then copper mining has entirely ceased.

The most productive lead veins of the county of Wicklow have been those worked in the mines at Glendalough and Luganure, of which the last only is at present in operation. The veins of this district have never presented any features of especial interest, excepting that courses of nearly pure galena three feet in width have occasionally been found in them; the veinstone is principally quartz. The yield of Luganure in 1881 amounted to only 822 tons of lead ore, containing 616 tons of lead and 4,932 oz. of silver. The only other Irish lead vein, from which Mr. Hunt's statistics give any returns for that year is Newtownards, County Down, which yielded 27 tons of lead ore, equal to 20 tons 10 cwts. lead, representing a value of £254. In 1894 the entire output of lead ore in Ireland was only 92 tons, valued at £367. The Government Geological Survey has shown that the copper and lead veins of Wexford, and probably those of Wicklow also, are older than the tin-bearing lodes of Cornwall.

Gold was doubtless obtained by the ancient Irish by washing the sands and gravels of certain streams and rivers. Gerard Boate, in his "Natural History of Ireland," published in 1726, mentions the occurrence of gold in Londonderry, since which time none appears to have been found there. Mr. Kinahan states that pieces of gold have in late years been picked up in the valley of the Dodder, and that quite recently a small nugget was found on St. Stephen's Green, Dublin, in a load of gravel which had been brought from the Dodder Valley.[1] In modern times gold was not generally known to exist in Wicklow until about a century ago, when it was remarked that persons from that part of the country occasionally brought small pieces into Dublin for sale. Not much attention appears to have been directed to the subject, until the finding of a nugget weighing 21½ oz. awakened public curiosity and caused inquiries to be made, the result of which was the discovery that it had been found in a rivulet flowing eastward, over Lower Silurian rocks, from the high granitic mountain of Croghan-Kinshella, on the borders of Wexford, and joining the Aughrim, a tributary of the Ovoca, at Woodenbridge. This discovery caused a great rush to take place in 1795, and a considerable amount of gold was collected by the diggers during the first six weeks, at the end of which time the Gold-mine Valley was taken possession of by the Government, while the operations of the country people were confined to the neighbouring streams of Knockmiller and Clonwilliam, Ballintemple, and Coolballintaggart, of which the last runs northward from Croghan-Kinshella. In addition to the washings along the beds of these streams, shallow placer workings were opened further north at Mucklagh, Ballinagappoge, and Ballycreen, on tributaries of the Aughrim or Ow River.

The Government works, under the superintendence of Messrs. Mills, King, and Weaver, were actively carried on until May, 1798, when they were interrupted by the Irish Rebellion, and not again resumed until the spring of 1801, when, in addition to the usual placer mines, a level or tunnel was driven into the eastern face of Croghan-Kinshella, and several miles of trenches were sunk to the bed-rock in various directions. In these workings numerous irregular branches of quartz were cut through, but in no instance was a particle of gold found *in situ;* and the alluvial gold having become practically exhausted the works were eventually abandoned.

The placer mining of the Government is said to have been remunerative, but the whole of the money thus realised was subsequently expended in trying to find gold in its natural matrix. The total amount obtained was 944 oz. which, when melted and run into bars, assayed on an average 21½ carats fine, and was at the price of the period worth £3,675. The alloy consisted of silver with a little copper. Sir R. Kane states that the gold collected by private individuals sold for above £10,000. Since the period referred

[1] G. H. Kinahan, *Geology of Ireland*, London, 1878, p. 340.

to, placer mining has at various times been resumed, but never with any marked degree of success.

Different observers have remarked that the auriferous gravels of Wicklow are invariably found at a lower level than the outcrops of certain neighbouring veins containing ores of iron and copper, through the disintegration of which the gold is supposed to have been liberated. But although gold is elsewhere often found in quartz containing various metallic sulphides, none has ever been discovered in the undecomposed portions of the mineral veins of Wicklow. Its presence has however been detected a little to the north-east in the gossans of the Ballymurtagh, Cronebane, and Connary Mines, to the west and east of the valley of the Ovoca. Some of the nuggets found have had, however, attached to them fragments of quartz, and it is consequently evident that a certain amount of auriferous quartz must exist somewhere in the neighbourhood.

According to Mr. Weaver the following minerals accompanied gold in the drifts and gravels of the Wicklow placers, namely, ilmenite, specular iron ore, red and brown hæmatite, iron pyrites, oxide of manganese, garnets, quartz, and chlorite. To these Mr. Mallet has added the following: platinum, cassiterite, wolfram, magnetite, molybdenite, galena, chalcopyrite, topaz, zircon, corundum, &c.[1]

Tinstone occurred more frequently at Ballinasilloge than in the higher ground near Ballinavally. The pieces of gold were, for the most part, much water-worn, but angular fragments were exceptionally met with. None of the gold diggings of Wicklow have been worked otherwise than as shallow placers, but since gold has been found in so many of the smaller tributary streams, it might be anticipated that, as in other gold-producing countries, it would be found in the deeper detritus on the banks of the larger rivers. These do not appear to have ever been explored, but Mr. Kinahan has suggested that gold may perhaps exist in paying quantities beneath the river and estuarine gravels at Woodenbridge and various other points in the valley of Ovoca. A few specks of gold have occasionally been found not only in the gossans at Ballymurtagh, Cronebane, &c., as already stated, but also in those of the copper lode at Carrigat or Dhurode, south of Bantry Bay, in the county of Cork.

Iron Ores of Miocene Age.—Iron-ore deposits belonging

[1] William Mallet, "On the Minerals of the Auriferous Districts of Wicklow," *Phil. Mag.*, xxxvii. 1850, p. 392. The presence of platinum was by no means satisfactorily determined by Mr. Mallet.

to this age represent an important feature of the Miocene rocks of Ireland; and, although usually classed as one series, they are believed to occur on slightly different geological horizons. They comprise beds of pisolitic iron ore, aluminous iron ore, bole and lithomarge, often associated with lignite. At some of the iron mines the thickness of these iron bearing strata exceeds 60 feet, while in others it scarcely amounts to as many inches.[1] The Tertiary rocks of Antrim comprise dolerites, basalts, and tuffs, the latter including the iron-ore measures, &c. The dolerite rocks may be divided into two series, the upper and the lower; the first of these being above the principal iron-ore measures, while the second is below them. The dolerites and basalts occur in the form of flows, protrusions, and dykes, while associated with them are bole and laterite with beds of ferruginous lithomarge and aluminous and pisolitic iron ore, in which last are occasionally beds of lignite.[2]

The dolerites are often somewhat coarsely crystalline and occasionally even porphyritic, and they not unfrequently exhibit a columnar structure; very large areas are covered by doleritic and basaltic rocks, but the tuffs are of more limited extent. The thickness of the flows of dolerite varies from a few feet up to 40 feet, while between them are accumulations of bole, a material closely resembling the laterite which, in India, covers to a great depth vast areas and contains deposits of nodular iron ore. In Ireland the thickness of these beds or partings seldom exceeds 70 feet. In some places the ferruginous accumulations graduate into aluminous iron ore of good quality, but in such cases they are not generally pisolitic, although the aluminous ores occasionally assume this structure if they come immediately in contact with a deposit of pisolitic ore. The beds of laterite between the flows of dolerite are usually of a reddish-brown colour, and are very tough. They have an amygdaloidal structure, and contain cavities enclosing arragonite with various zeolites.

The partings between the lower beds of dolerite are generally softer than those dividing the upper series, and frequently graduate into either ochre or bole. This does not take place so frequently between the upper dolerites, but in all cases, the iron ore alone excepted, the material constituting the dividing beds is throughout vesicular.

The iron-ore measures of Antrim vary in thickness from 10 to

[1] G. H. Kinahan, *Geology of Ireland*, p. 164.

[2] Philip Argall, "Notes on the Tertiary Iron Ore Measures, Glengariff Valley, County Antrim," *Proc. Roy. Dublin. Soc.*, iii. 1881, p. 151.

70 feet; in the Glengariff Mines they do not, according to Mr. Argall, exceed 60 feet, and, with the associated rocks, afford the following section:—

		Feet.
TERTIARY	Upper dolerites	300
	Iron-ore measures	60
	Lower dolerites	250
	Basal conglomerate	2
CRETACEOUS . . .	White limestone	70
	Total	682

The iron-ore measures are composed as follows:—

			Ft.	in.
6. Steatitic rock ; local name	Brushing		0	8
5. Steatitic clay	,,	Holing . . 1 in. to	0	3
4. Pisolitic ore	,,	First ore	1	7
3. Aluminous ore	,,	Second ore . . .	2	6
2. Ochreous rock	,,	Pavement	15	0
1. Lithomarge	,,	Marge	40	0
		Total	60	0

The lithomarge usually rests upon an irregular flooring of dolerite, which is in places corroded into deep holes. Boulders and masses of dolerite, externally much decomposed, are also found embedded in the bottom beds of the lithomarge and often pass insensibly into this rock. The lower beds of lithomarge are usually of a light lavender tint, and contain numerous small spots of bauxite; while the upper layers are brown or nearly black. It is a brittle, splintery rock, which flies before the pick, but is nevertheless readily cut with a knife. In the immediate vicinity of an eruptive dyke it becomes a very tough rock, and on exposure to the atmosphere it rapidly exfoliates. Interstratified with lithomarge are deposits of aluminous iron ore, usually in the form of beds varying in thickness from a few inches to several feet; but they sometimes also occur as lenticular intercalations. Small partings and seams of a siliceous lignite are sometimes found in the aluminous ore as well as in the pisolitic variety, but seldom or never occur in the lithomarge. It has been observed that when peat water flows over an exposed surface of lithomarge a deposit of oxide of manganese frequently takes place in its cavities and interstices.

The ochreous rock above the lithomarge is called the "pavement," and forms the floor of the iron-ore measures. It seldom contains bauxite, excepting in the immediate vicinity of a dyke, where considerable masses of that substance frequently occur.

On the pavement rests the aluminous or second iron ore, the upper portions of which are to some extent pisolitic, and on this lies the first or pisolitic ore. The pisolitic ore varies considerably in thickness, but sometimes reaches 30 inches. In colour it is either brown or black, some of the pisolites of the latter colour having the appearance of graphite. These are more or less magnetic, many of them consisting chiefly of magnetite. The pisolitic iron ore usually contains from 30 to 70 per cent. of iron oxide, from 2 to 10 per cent. of alumina, from 5 to 10 per cent. of silica, and from 9 to 11 per cent. of titanic oxide. Sulphur is entirely absent, and only minute traces of phosphorus are occasionally present. The aluminous ores contain from 25 to 35 per cent. of iron, from 34 to 37 per cent. of alumina, and from 12 to 16 per cent. of silica. They are free from sulphur, only occasionally contain traces of phosphorus, and titanic oxide is entirely absent. These ores are largely employed as a mixture in smelting hæmatites.

Lignite and bauxite occur in the iron-ore measures of County Antrim, and usually replace the pisolitic seam, although in some places the lignite is separated from the ore by a band of bauxite. Intervening between the pisolitic ore seam and the roof are two beds of steatitic clays, known respectively as "holing" and "brushing." These clays contain numerous pisolites of arragonite, and similar nodules of that mineral are by no means uncommon in the lower bands of dolerite. The iron measures of Antrim are often penetrated and displaced by basaltic dykes, whose general bearing is a little east of north, and which vary in thickness from a few inches to several fathoms. They have frequently a columnar structure, the bases of the columns being nearly at right angles to the walls of the dykes.

These iron-ore measures are supposed to be of lacustrine origin, and to have been formed in shallow expanses of water in basins resulting from successive but unequal flows of dolerite. Lignite occurs in this rock near Crumlin, east of Lough Neagh, Carnmoney, south-west of Carrickfergus, Ballypalady, east of Antrim, also in the face of the cliff near the Giant's Causeway, and at Dunagael, Rathlin Island. Generally speaking, lignite is more or less associated with the ironstone measures, but in some cases it occurs between beds of dolerite. At Lemeneigh, west of Ballintoy, the lignites contain blocks of wood which split with great facility, while, still further west, the wood is but slightly mineralised and remains very much in its original condition. In the clay below the lignite are found plant remains, one of which is considered by Baily to be *M'Clintockia Lyellii*, a plant previously found only in Greenland.

The principal localities at which pisolitic iron ores have been worked are along the outcrop of the beds from Knockboy and Ballylig, near Broughshane, to Glenravel, Cargan, and Newtown Crommelin, on the sides and at the head of Glengariff, near Carnlough and Glenarm, at Shane Hill, west of Larne, on Island Magee, at Ballypalady, near the Giant's Causeway, and a little inland from the White Rocks near Portrush. The whole of the workings are in the country lying north and north-east of Lough Neagh.

During the year 1881 there were exported from County Antrim 198,429 tons of this ore, the only other iron ores produced in Ireland being gossans from Ballymurtagh, County Wicklow, amounting to 1,433 tons. In 1894 the production was 76,471 tons of iron ore, valued at £14,689, and 7,970 tons of bauxite, valued at £5,618. Together with these there were produced in various parts of Ireland 7,800 tons of impure bog ore, chiefly used for purifying coal gas.

Other Mining Localities.—That workings for copper ore were carried on at a very early period in the Bonmahon district, County Waterford, is rendered evident by a number of ancient wooden mining tools, which were discovered by Mr. Petherick in some old workings on the Stage Lode at Knockmahon. During the course of the last century the Knockmahon mines were worked at different intervals and with somewhat varying success; in the aggregate, however, they have produced large quantities of copper ore and have sometimes yielded considerable profits to the adventurers. The lodes, which traverse Silurian rocks and are intersected by numerous cross courses, are, according to Kinahan, of Pre-Carboniferous age, and are cut off by certain red conglomerates and sandstones, probably of Old Red Sandstone age. The general direction of the lodes is west of north, and the ground is traversed by various dykes of quartz-porphyry. The lodes at Knockmahon have, however, been worked down into very poor ground, and operations were ultimately suspended in the year 1880.

Some rich lodes, unknown to the ancients, were discovered about the year 1810 at Allihies, west of Bearhaven; and, under the name of Bearhaven Mines, have since been successfully worked and have yielded large quantities of copper ore. The mines have now attained a depth of above 250 fathoms, but the returns had fallen off considerably by 1880, and soon ceased altogether. The lodes occur at the junction of the Yellow and Old Red Sandstone of the Cork type; in 1881 the annual production of the Bearhaven Mines was not above 832 tons of copper ore of $8\frac{3}{4}$ produce and of the aggregate value of about £4,500. The slaty regions, extending from Cork to the Mizen Head and beyond that point northward, enclose small veins containing copper ores of high percentage, such as erubescite and tetrahedrite; but, with the exception of Bearhaven, no great degree of success has hitherto attended mining operations in this part of Ireland.

With the exception of the very few tons of galena already mentioned, Ireland has recently produced no metalliferous minerals at all except the iron ores and iron pyrites previously referred to.

Scotland.

Although the earliest documents relating to mining in Scotland do not go further back than the twelfth century, the testimony of Roman writers and the number and variety of the prehistoric gold ornaments which have from time to time been found in that country render it probable that the early population had worked the native sources of supply at a period long anterior to the beginning of written history. The first historical notice of gold occurring in Scotland is a grant in 1153 by David I. to the abbey of Dunfermline of a tithe of all the gold from Fife and Fothrif; and, in 1424, the Scottish Parliament granted to the Crown all the gold mines in Scotland.[1]

A document from the Balcarres MSS., printed in the *Analecta Scotica*, first series, pp. 91–94, shows that between the years 1585–1590, lead ore, to the amount of 15,717 stone, had been shipped from Scotland for foreign use. In the year 1593, Thomas Foullis obtained a take of all the mines in the sheriffdom of Lanark; and in 1707 an act of parliament exonerated and discharged Charles, Earl of Hopetoun, from a rent of 1,000 marks payable by him to the Crown in terms of the original grant. Another act gave him the right to pass the bridge of Ramwell Craig and Dunneden with lead ore and supplies for the mine and miners free of toll. This privilege was shared with the Duke of Queensberry.

[1] R. W. Cochran-Patrick, *Early Records Relating to Mining in Scotland*, Edinburgh, 1878.

Gold.—As far as is at present known, the gold fields of Sutherland are all comprised within a radius of about ten miles around Benuarie, the gold having, for the most part, been found along the valleys of the tributaries of the Ullie or Helmsdale River.[1]

The principal streams which have been worked are the Kildonan, where gold was first discovered, the Suisgill, and the Torrish; these streams constitute what are known as the Kildonan diggings. Gold has also been found in the Altenbraichich, the Cinpreas, and the Craggie, all flowing into the Ullie. On the south side of the dividing range, called the Crask, gold has been found in the Smeorol, a burn which falls into Loch Brora at Gordon Bush, and hence called the Gordon diggings. Further west, on another tributary of the Brora, known as the Black Water, gold has been likewise found.

The prominent geological features of the country are rocks which are regarded as being mainly of Lower Silurian age, consisting of granites, gneiss, mica schist, and quartzite, which, in a few localities only, are traversed by veins of quartz. Along the coast is a belt of coarse-grained granite. Old Red Sandstone sometimes caps the Silurian rocks, and Oolitic shales are found near the sea above the valley of the Brora. In the streams in which gold has been most plentifully found, gneissoid and schistose rocks prevail, while the higher ground is everywhere so thickly covered by a deep deposit of peat that it is only at points situated at considerable distances apart that any rocks are exposed on the surface. In the beds of the rivulets on the high ground of the Kildonan hills, schistose and flaggy rocks largely predominate, and in the interstices between their laminæ gold is sometimes found.

On either side of the Kildonan, high moorland hills trend towards a range of quartzite running parallel with the Ullie, and confine the stream and its littoral flats within very narrow limits. Tributaries occasionally flow into the main burn and often afford good sections both of the rocks and drifts, the latter usually yielding a little gold. In some places the Kildonan itself has cut its way through beds of rock outcropping at the surface, while in others high banks of sand and pebbles afford evidence of extensive alluvial deposits. These flats are occasionally flanked by deep terraces of gravel and drift, from the surface of which, mixed with angular fragments of granite, grains of gold may sometimes be obtained by panning.

[1] W. Cameron, "On the Sutherlandshire Gold Fields," *Trans. Geol. Soc. of Glasgow*, iv. 1874, p. 1.

Towards the lower portion of the stream the rocks assume a more granitic character, and are associated with gneiss, micaceous and chloritic schists, and quartzites, which are occasionally traversed by veins of quartz. In some parts of the course of this stream, granitic masses assume the form of dykes, and gold appears to be most plentiful when the stream forms an acute angle with the strata crossing its bed. As a rule the miners preferred working either in the vicinity of masses of granite, or in the neighbourhood of a partially decomposed greenish schist. The earlier operations of the diggers were exclusively confined to the banks of the streams where the bed-rock was above the level of the water. The gold was found chiefly in the lower drift, but it has been also obtained from all the various strata even up to the roots of the heather. The drifts vary materially in character, having sometimes the appearance of a ferruginous conglomerate, while in others the auriferous material is a yellowish felspathic detritus. The small proportion of rounded quartz pebbles and boulders, or in some instances their entire absence, would be considered remarkable by a person accustomed to the placer diggings of California or Australia. In nearly all cases the material which remains when the process of washing draws towards completion is found to contain, along with the gold, a considerable proportion of titaniferous iron ore and magnetite together with a few small garnets. As before stated, the auriferous detritus is generally almost entirely composed of somewhat water-worn fragments of the local rocks; but in a few instances pebbles from the Old Red Sandstone and nodules of red hæmatite have been found among it. Latterly the miners no longer confined their operations to the shingle immediately bordering the streams, but advanced for some distance into the flats forming their banks, although with but very moderate success.

The Suisgill is a burn of about the same size as the Kildonan, but is flanked by deeper deposits of drift and by more extensive flats than that stream. In this rivulet the gold is coarser than that found in the Kildonan, and it is here that a two-ounce nugget is said to have been found. The same rocks present themselves along the course of the Suisgill that are seen in the bed of the Kildonan, although the latter affords better sections. Nearly all the other streams exhibit similar peculiarities, and a description of them is consequently unnecessary. It is evident that gold in small quantities is generally distributed throughout this part of Scotland, but there appears to be considerable difference of opinion with regard to its derivation. Sir R. Murchinson believed the gold-bearing drift to have been brought from the Silurian plateau towards the central and western portions of Sutherlandshire, while Mr. Campbell of Islay is inclined to the opinion that at least a portion of it may have come from even Scandinavia or Lapland; both, however, consider the vehicle of transport to have been ice. No gold has yet been found in this district *in situ*, and consequently no definite proof exists of its local origin. The drift is, however, composed of fragments of purely local rocks, while quartz pebbles, usually so plentiful in deposits of this nature, are almost entirely wanting. Influenced by these and similar considerations Messrs. Joass and Cameron are disposed to ascribe a granitic origin to the gold of this area. It is, however, possible that it may have been derived from the quartz veins which are seen in the ravines through which the streams severally flow, or from others which are now hidden under a covering of bog or other material.

Whether the gold which occurs in these drifts could under ordinary circumstances afford remunerative occupation to any considerable number of men, is open to grave doubt. When, however, it is stated that a tax of one pound per month was levied by the Duke of Sutherland upon each miner for the privilege of digging for gold upon his waste lands, and that the Government further demanded one-tenth part of the gold found as royalty, it will be easily understood why gold washing in this district was an industry of short duration.

An interesting experiment has recently been tried by the Sutherland County Council, who arranged for a number of men to wash gold in the Suisgill burn for three months, from May 6th to August 6th, 1895. Seven men were allowed to work and the results obtained are shown in the following table[1]:—

	Time at Work.	Weight of Gold brought in.		
		oz.	dwt.	gr.
I.	May 6th to Aug. 6th . .	4	3	12
II.	,, ,, ,, . . .	3	11	0
III.	May 7th ,, ,, . . .		15	5
IV.	June 3rd ,, ,, . . .		14	9
V.	,, ,, ,, . . .		14	9
VI.	June 15th ,, ,, . . .	2	12	11
VII.	July 16th ,, ,, . . .		5	2
	Total production	12	16	0

[1] Communicated by Archd. Argo, Esq., County Clerk.

It will be seen that the above total, worth probably from £45 to £50 was obtained by the labour of 476 days, or about 2*s.* per day, while the best result is nearly double this. Unfortunately no accurate record of the amount of ground worked has been kept. It seems that the area worked was approximately from one-fourth to one-third of an acre, whilst the average depth of the excavation was about three feet. Taking the larger estimate, this would make the amount of ground worked about 1,600 cubic yards or 3·84 grains of gold to the cubic yard. This proportion has paid very well in California where cheap water power at high levels was available, and when there was a great depth of pay gravel, but these conditions do not exist in this district, where the total quantity of auriferous gravel seems to be insignificant. It was found that the heaviest gold was got in the bed of the burn, and that further away it only existed as flour gold. The miners do not seem to have attempted to save the latter by using mercury.

LEAD, SILVER, AND NICKEL.—There are lead mines in the south of Scotland at Wanlock Head, now called the Queensberry Mines, in Dumfriesshire, and at Leadhills in Lanarkshire, where the veins occur in Silurian rocks. At Cally, in Kirkcudbrightshire, copper ore has been discovered, and stibnite has been found in the county of Dumfries. In neither case have they been turned to any account, although a small quantity of lead ore is annually produced in the first-named county. The lead mines of Strontian, in Argyllshire, were once of some importance, and a lead mine in schist has been worked at Tyndrum, and another in the Isle of Islay. Pentlandite, a sulphide of iron and nickel, was some years since, worked at Glen Essochossan, two miles from Inverary, as well as at Craignure, in the vicinity of Loch Fyne, eight miles distant from the same town. About 300 tons of ore averaging 14 per cent. of nickel are stated to have been sold from these mines. In a sample of the ore from the Craignure Mine Mr. F. Claudet found, in addition to the usual percentage of nickel, a considerable amount of tin oxide.

Writing towards the latter portion of the eighteenth century Jars[1] states with regard to Leadhills :—" Le filon principal produit jusqu'à la plus grande profondeur où on l'exploite, de 100 pieds

[1] "Up to the greatest depth to which it is worked, 100 feet below the adit, the principal vein produces very beautiful spar, lead ore with large irregular and cubical faces, green, black, and non-crystallised white ore, the latter also in white and very friable crystals. This variety is very beautiful and extremely rich in lead. I have seen this vein worked for a very great distance with a width of at least four feet in massive ore ; and I am assured that it enlarged as the depth increased, as at its greatest depth it is seven feet. This vein is one of the richest

au-dessous de la galerie d'écoulement, du très-beau spath, du minérai de plomb à larges facettes, irrégulieres et cubiques, de la mine verte, de la noire, & de la blanche non-crystallisée, & de cette derniere en crystaux blancs & très-friables ; cette espèce est très-belle & extrêmement riche en plomb. J'ai vu exploiter ce filon sur une très-grande étendue, au moins de 4 pieds de largeur en minérai massif, & l'on m'a assuré qu'il s'élargissoit en approfondissant, puisqu'à sa plus grande profondeur il en avoit 7. Ce filon est un des plus riches qu'il y ait en Europe, je n'ai encore rien vu qui approche de cette abondance."

John Mawe,[1] writing at the beginning of this century, says: "The veins are in general large and extremely rich. The Susanna vein is the admiration of travellers, being a great rake vein which in some places has continued for a considerable way fourteen feet wide of solid ore. It is now full three feet wide and an amazing quantity is before the miners. The mine is about 100 fathoms deep with a fire-engine not now employed, a sufficient quantity of water having lately been procured to work the water-engines so as to keep the bottom dry." The mines of Strontian, in north-western Scotland, afford an example of the occurrence of lead veins in granite.

In 1881 the Leadhills produced 1,804 tons of lead ore containing 5,412 oz. of silver, of the total value of £17,138.

During the year ending June 1883 the quantity of ore dressed was 2,891 tons; 2,115 tons of ore were smelted, producing with the fumes, 1,693 tons of lead. In 1894 the Leadhills produced 1,876 tons of lead ore which yielded 1,390 tons of lead, and 7,299 oz. of silver, and was worth approximately £10,000.

In 1881 the Queensberry Mines, late Wanlock Head, yielded 1,826 tons of lead ore containing 8,000 oz. of silver, worth £17,347. In addition to the above the East Black Craig Mine, in Kirkcudbrightshire, yielded 176 tons of lead ore, value £1,628. During the same period 232 tons of copper ore, value £468, were produced in Shetland, and 323 tons of blende, value £607, were raised at the East Black Craig and Queensberry mines. In 1894 the Queensberry mines produced 2,152 tons of lead ore yielding 1,697 tons of lead and 11,863 oz. of silver, and valued at about £20,000; also 160 tons of blende, worth £560.

Blackband Ironstone.—In Scotland the coal-bearing strata lying above the Millstone Grit are known as the Upper Coal-

in Europe—I have not yet seen anything which approaches to it in abundance."—*Voyages Métallurgiques*, ii. p. 531, Paris, 1780.

[1] *Mineralogy of Derbyshire, &c.*, London, 1802, p. 137.

measures, while the seams of coal in the Carboniferous Limestone belong to the Lower Coal-measures. These measures stretch across the country in a south-westerly direction from the German Ocean to the North Channel. In addition to coal both the upper and lower series contain valuable seams of blackband ironstone. This term is applied to ironstones of a dark brown or black colour containing a sufficient amount of carbonaceous matter to enable them to be burnt in heaps without the addition of extraneous fuel. When thus burnt the residues often yield from 50 to 70 per cent. of metallic iron. Blackband ironstone is found both in the upper and in the lower series.[1]

The Upper contains—

	Thickness.
The Palace Craig Blackband	12 inches.
,, Airdrie	16 ,,
,, Bellside	6 ,,
,, Kiltongue	about 6 ,,
,, Calderbank or Kennelburn	,, 10 ,,
,, Slatyband	from 12 inches to 3 feet.
,, Lower Slatyband	,, 12 ,, ,, 18 inches.

The Lower series contains—

The Possil Upper Blackband	12 inches.
,, Possil Lower	12 ,,
,, Banton	12 ,,

All these ironstones have been found in some part of Lanarkshire, the principal seams being the Airdrie Blackband and the Slatyband. The former, now nearly exhausted, has been found in workable quantity within an area of only about ten square miles, but its equivalent in the form of a thin seam of coal covers an area of from fifty to sixty square miles. The Slatyband extends over a considerable area, but is variable both in thickness and quality, sometimes gradually thinning out and disappearing. It is found in Lanarkshire, Ayrshire, and Fifeshire, though in the last-named locality it is not of good quality. In Linlithgowshire it is represented by the celebrated Boghead cannel coal.

Blackband was discovered in Lanarkshire by Mushet in 1801, and has for many years been very extensively worked, but at the present time the supply is very rapidly falling off. The yield of blackband ironstone is at the rate of 2,000 tons calcined ore, equivalent to 1,000 tons pig iron, per acre for each foot in thickness.

Clay ironstone is worked in connection with the Shotts

[1] Ralph Moore, "On Coal and Ironstone Mining in Scotland," *Proc. S. Wales Inst. of Eng.* iii. 1864, p. 239.

Furnace Coal and the Ball or Coalinshields Coal, and two bands of clay ironstone occur in the underlying Millstone Grit series, namely, the Ginstone and the Curdley or Curly ironstone. Clay-band ironstone of good quality was formerly obtained at Banton and Denny in the Carboniferous limestone series. Several seams of the same mineral have been mined at Falkirk among the strata immediately overlying the Slatyband ironstone. This ore has also been obtained from the horizon of the Brighton Main and the Auchingane coals. Of the 2,595,375 tons of ironstone produced in 1881 in Scotland, 1,402,700 tons were Blackband, and 1,192,675 tons Clayband. By 1894 the output of Scotch ores had diminished very markedly, the total output for that year, nearly all of clay band, being 631,304 tons valued at £242,168.

General Summary of the Production of Metalliferous Minerals in the United Kingdom during the year 1882.[1]

Description of Ore.	Quantities.	Values.
	Tons.	£
Iron ore	18,031,957	5,779,285
Bog iron ore	5,872	1,957
Tin ore	14,045	805,847
Copper ore	52,810	206,738
Lead ore	65,001	592,610
Zinc ore	32,539	93,571
Iron pyrites	25,403	14,459
Cobalt and Nickel ore	38	241
Manganese ore	1,548	3,907
Wolfram	58	747
Arsenical pyrites	12,564	11,614
Total value of metalliferous minerals		£7,510,976

The production of metalliferous minerals in Great Britain has been for many years steadily diminishing; at present its value is less than one-half of that of the slates and stones quarried in the kingdom, and only about one-fifteenth of that of the coal raised, so that the metallic minerals contribute a comparatively insignificant proportion to the value of the total mineral output, nor does there seem to be much probability of any very marked improvement in this direction.

For the sake of comparison the production of metalliferous minerals in the years 1888 and 1894 taken from the Annual Statistics published by the Home Office is here subjoined :—

[1] "Mineral Statistics of the United Kingdom for the year 1882, prepared by Her Majesty's Inspectors of Mines." London, 1883.

Description of Ore.	1888. Quantities.	1888. Values.	1894. Quantities.	1894. Values.
	Tons.	£	Tons.	£
Bauxite	9,666	4,833	7,970	5,618
Arsenic	4,624	35,197	4,801	48,614
Arsenical pyrites	5,325	4,240	3,288	3,823
Bog Iron ore	10,927	5,463	7,803	1,951
Cobalt and Nickel ore	152	746	—	—
Copper ore	15,132	60,980	5,753	13,909
Copper precipitate	418	6,539	241	2,313
Gold ore	3,844	27,300	6,603	13,573
Iron ore	14,590,713	3,501,317	12,367,308	3,190,647
Iron pyrites	23,507	11,302	15,523	8,042
Lead ore	51,259	438,383	40,600	266,995
Manganese ore	4,342	1,934	1,809	740
Ochre, Umber, &c.	7,573	13,387	8,516	14,040
Tin ore	14,370	894,665	12,910	487,523
Uranium ore	—	—	19	815
Wolfram	60	1,625	—	—
Zinc ore	26,408	96,984	21,821	67,311
Total values of metalliferous minerals		5,104,895		4,125,914

FRANCE

Metal mining in France is of very ancient origin, as the Gauls were familiar with gold, silver, lead, copper, tin and iron, previous to the Roman conquest of the country. Under Roman government metalliferous mines were extensively worked, but at the time of the Northern invasion they were generally abandoned. At a later date mining was resumed by the Saracens, who carried on that industry in the Pyrenees and in various other districts, but it was not until nearly the end of the eleventh century that the mines of France assumed any distinctive importance. In the thirteenth century mining was again generally abandoned in consequence of long-continued wars, and the mines were not re-opened until the commencement of the sixteenth century. During the Thirty Years' War operations were again arrested, and it was not until the beginning of the eighteenth century that some prosperous mining undertakings were carried on in Brittany, in the Pyrenees, and in Central France. This prosperity of mining enterprise was however only temporary, and it is somewhat remarkable that, with the exception of those of iron ores, comparatively few of the metalliferous deposits of France are rich enough, and at the same time sufficiently easy of access, to repay the expenses of working.

France has no valuable gold mines, but the sands of some of her rivers are to a small extent auriferous. The only vein known to contain gold in appreciable quantities is that of La Gardette, in the Department of Isère, which is from two to three feet in width, and is enclosed in gneiss. Gold was discovered in this locality in the year 1700, and workings were intermittently carried on up to 1841, the most active period having apparently been about 1780, but the aggregate amount of the precious metal obtained was very small. From 1841 to 1862 it seems to have been worked fitfully as a "specimen" mine, but no serious work seems to have been done. At the same time there seems to be some pretty conclusive evidence to show that the vein here is permanent, but that it becomes poor in depth.[1] The Rhine, until recently forming for some distance the eastern boundary of France, for centuries yielded small quantities of gold, and, according to a report of Réaumur presented to the Academy of Sciences in 1718, its sands had been chiefly worked between Strasburg and Philippsburg. The gold of the Rhine in the vicinity of Strasburg formerly belonged to the magistrates of that city, who farmed out the gold-washing on a royalty, but in the year referred to they only received some four or five ounces as their proportion of the annual produce. In the year 1846 Daubrée made an exhaustive report to the Academy of Sciences in which he states, that the gravels most commonly worked were those deposited below sand-banks or gravel islands which have been eroded by the river; and that the gold is chiefly concentrated in the coarser gravels which have been freed from silt and fine sand by the action of currents.[2] The gold usually occurs in the form of minute scales, and is constantly accompanied by titaniferous iron ore, the amount of which is proportionate to the richness of the original sand in the precious metal. The workable beds are invariably thin, seldom exceeding six inches in thickness, and the particles of gold are exceedingly small, since the number required to weigh one milligramme varies from 17 to 22, while one cubic metre of gravel contains from 4,500 to 36,000 of such scales. In addition to the auriferous deposits which accumulate in the bed of the stream, Daubrée states that the ancient detritus on its banks, extending from three to four miles in width, also affords an appreciable amount

[1] T. A. Rickard "La Gardette," *Trans. Amer. Inst. M. E.* xxi. 1892, p. 79.

[2] *Comptes Rendus*, xxii. 1846, p. 639.

of gold, but that the fine silt free from gravel may be regarded as totally barren.

The sands of the Rhine are still occasionally washed upon a small scale, but it is believed their production was formerly more considerable than it is at present. The yield of the year 1846 was estimated at £1,800, the washers usually making from one and a half to two francs per diem, although they occasionally realised from ten to fifteen francs. After a very careful study of the whole question Daubrée arrived at the conclusion that, by the aid of proper appliances, these sands might possibly, at that time, be treated with advantage. Some of the operations were evidently capable of improvement, since the washing was entirely conducted by manual labour, although the motive power of the river itself might, if applied to a dredging machine, be easily made to remove the richer gravels and to deposit them at the head of a properly arranged sluice. Although the application of machinery might doubtless in this and other ways be made to materially lessen the expense of washing the sands of the Rhine, the yield of gold is so exceedingly small that it is nevertheless doubtful whether by any known method of treatment satisfactory results could be obtained.

Several localities in France have from time to time afforded small quantities of gold, the River Ariége (*Aurigera*) being said to have derived its name from its auriferous sands. The washing of these up to the close of the fifteenth century is stated to have yielded nearly a hundred pounds weight of the precious metal annually. Small quantities of gold have been also sometimes obtained by washing a conglomerate of Carboniferous age, in the vicinity of Bessèges, Département du Gard, where traces of gold occur in the quartzose pebbles of the Millstone Grit.

The production of gold in France during the year 1880 is officially stated to have been 31 kilogr. or 996½ oz., but the ores from which it was obtained were probably, in part at least, derived from foreign sources.

Iron ores are produced in over thirty of the départements of France, the largest proportion by far, ranging from one-half to two-thirds of the total, coming from the Meurthe-et-Moselle. The ore chiefly worked here is that of the stratified oolitic deposits, to which reference has already been made (p. 44). It forms a portion of the extensive bed of ore which supplies the largest proportion of the iron ore raised and consumed in Germany, Alsace-Lorraine, and Luxembourg, as well as in France. In the département of Meurthe-et-Moselle there are two main centres of production of about equal importance, namely, Nancy and Briey including Longwy. The mineral, which consists of a hydrated oxide of iron of highly oolitic structure, occurs at the contact of the Upper Lias and the Inferior Oolite in the so-called Toarcian beds. The beds of ore dip at flat angles. There are usually three, separated by beds of shale; the entire thickness of the ferriferous strata in this département is about 100 feet, but not more than 3 or 4 feet thick can be worked as a rule. These deposits are in many respects comparable to the Cleveland ores and have like them probably been formed metasomatically, but have undergone subsequent alteration. This deposit has for years past produced from two to three millions of tons of ore per annum in France. In the same département another form of deposit, consisting of pockets of an oolitic hæmatite in the oolitic limestone, has been worked to some extent, though not since 1882.[1]

Similar deposits, but of a slightly different geological age (Bajocian = Inferior Oolite), have been worked at Privas in the département of Ardèche and various other places. These were at one time very productive, their output in 1868 having been about 160,000 tonnes per annum, according to Fuchs and Delaunay (*loc. cit.*); twenty years later their output had fallen greatly, that of the whole département having been only 93,000 tonnes in 1868, and 62,000 tonnes valued at 377,000 francs (about £15,000) in 1890; to these latter totals the mines of La Voulte, likewise a bedded deposit of Oolitic age, also contributed.

At Mazenay and Changes (département of the Saône-et-Loire), the Creuzot Company works deposits which seem to be either contact veins or else large flat irregular deposits of lenticular shape between certain beds of crystalline limestone and shales of Liassic age. This deposit too seems to have been most productive in the year 1868 when it yielded 250,000 tonnes; in 1890 it produced 128,000 tonnes valued at 400,000 francs (£16,000). Pockets of iron ore in Jurassic limestone are worked at Berry (département of Cher).

The small amount of clayband carbonate that used to be got in some of the coal measures, especially in the basin of the Loire, was in 1894 quite insignificant. At Alleward and Vizille (département of Isère) spathic ore in veins cutting across micaceous and talcose schists of Triassic age is being mined; veins of spathic ore, altered

[1] Fuchs and De Launay, *Traité des Gites Minéraux et Métallifères*, Paris, 1893, p. 779.

in the upper portions to red and brown hæmatites and locally to magnetite, have been and are still actively worked at Canigou in the Pyrenees; a mass of granite has here pierced the surrounding stratified rocks, and along an ellipsoidal zone, having a maximum diameter of about ten miles, where the two different rocks come in contact with one another, are numerous deposits of carbonate and oxide of iron. In this way the mines of Batère, Rocas-Negros, Droguère, Olette, Fillols, Vellestavia, Saint-Martin, &c., are arranged around the central mass of granite.

In 1888 the output was 6,900 tonnes of spathic and 33,400 tonnes of hæmatite ore. Somewhat similar deposits in bedded veins are also worked on the Mountain of Rancié near Vicdessos (département of Ariége), the production for 1890 having been 11,228 tonnes. These mines some years since kept no less than fifty Catalan forges constantly supplied with suitable ore, and are known to have been worked during a period of more than six hundred years. The enclosing rocks are white granular limestone, a less crystalline gray calcareous rock, and argillaceous schists of Jurassic age. The iron deposits of Rancié occur in nearly vertical deposits, one of which is so permeated by brown and red hæmatite, spathose iron ore, and occasionally with oxide of manganese, that ore frequently becomes the prevailing material. The limestones are often much coloured by oxide of iron, and are traversed by numerous veins of pure hæmatite containing druses lined with concentric layers of brown and red oxide of iron. This deposit, which has an average thickness of about sixty-five feet, can be traced from the bottom of the mountain to its summit, a height of 1,970 feet, while its inferior limit has never yet been reached. The parallelism of this formation with the surrounding strata caused them for a long time to be regarded as being of contemporary origin, but M. Dufrénoy, who some years since examined this deposit, inclined to the opinion that the deposition of iron ores took place subsequently to that of the enclosing strata.

At St. Renny in the département of Calvados and in the district of Segré (Maine-et-Loire), beds of red hæmatite in Silurian quartzites are worked, and a similar deposit, in which the beds, standing on edge, occur in metamorphic rocks resting against a boss of granite, was worked as recently as 1892 beneath the sea at Drélette, in the département of La Manche.

The table on next page, showing the output in tonnes of the various départements, will give a clear idea of the state of iron ore production in France:—

Production of Iron Ore in France.

Départements.	1880.	1885.	1890.	1894.
	Tonnes.	Tonnes.	Tonnes.	Tonnes.
Meurthe-et-Moselle .	1,658,000	1,612,000	2,630,311	3,062,373
Saône-et-Loire . . .	160,000	116,000	128,686	104,351
Haute Marne	195,000	147,000	116,178	155,254
Lot-et-Garonne . . .	—	45,000	81,325	51,320
Ardèche	190,000	70,000	62,059	23,605
Gard	88,000	53,000	61,179	57,575
Pyrénées-Orientales .	98,000	55,000	60,280	57,962
Calvados	30,000	22,800	58,777	97,433
Cher	102,000	54,000	54,000	29,513
Manche	12,000	35,000	51,359	—
Isère	53,000	24,200	46,320	46,538
Loire Inférieure . . .	12,000	4,300	44,093	7,757
Miscellaneous	276,000	79,700	77,433	78,420
Totals	2,874,000	2,318,000	3,472,000	3,772,101

The following table gives the production of the various kinds of iron ore in France in the respective years :—

Nature of Ores.	1880.	1885.	1894.
Oolitic hydrated ores . . .	1,841,000	1,861,400	3,348,000
Other hydrated ores	554,400	151,700	154,000
Red hæmatite	242,400	97,900	130,000
Brown hæmatite	107,500	146,100	79,000
Spathic ore	103,400	51,200	61,000
Clay ironstone	5,800	—	—
Magnetite	19,700	9,700	—
	2,874,200	2,318,000	3,772,000

Copper mines have been worked in the départements of Var, Gard, Basses-Pyrénées, and in Savoie, but their aggregate production of merchantable ore during the year 1880 amounted to only 550 tonnes, whilst no productive copper mines existed in France in 1894. Zinc ores are produced in various parts of France, but the most important are those of Saint Laurent-le-Minier, Gard, which yielded about one-half of the annual production of the country in 1880. Within the last ten years the production of zinc ores has increased enormously, having risen from 12,000 tonnes in 1880 to 56,500 in 1891, in which latter year the département of Gard produced 23,770 tonnes, and Var 20,670. In 1894 the production of France was nearly 77,000 tonnes, to which total the above départements contributed 39,300 and 29,300 tonnes respectively.

Burat[1] divides France into five metalliferous districts, namely:—the promontory of Brittany, bounded by a line extending from Contentin, passing near Alençon and Angers, and terminating in the vicinity of Parthenay; the mountainous range of the Vosges, forming a kind of island surrounded by sedimentary rocks; the great plateau of Central France; the Pyrenees; and the Alps.

BRITTANY.—Both with regard to its geographical position and its geological constitution, Brittany closely resembles Cornwall, being like it a region largely composed of clay slates broken through by granite, traversed by dykes of porphyry, and penetrated by masses of serpentine. In spite, however, of these analogies the metalliferous deposits of the two countries are of very unequal importance. In Brittany the tin veins of Cornwall are but feebly represented, copper lodes do not exist, and mines of argentiferous galena, similar to those of North-Western Cornwall, exist but are not very actively wrought.

Oxide of tin has been found in small quantities in various localities, particularly at Pyriac, two and a half miles west of the mouth of the Loire, and at the Moulin de la Villeder, Morbihan. At Pyriac the clay slate is in contact with the granite, and at their point of junction there is an alternation of schistose and granitic or gneissic rocks containing oxide of tin, which occurs either disseminated through thin veins of quartz or in the form of small concretionary masses. A considerable amount of prospecting was carried on at this place in 1818, but although about 10 cwts. of tinstone were collected, no workable or regular deposit of that mineral was discovered.

At the Moulin de la Villeder, near the rock Saint-André, a vein of stanniferous quartz is enclosed in granite. Its direction is N. 34° W., and the veinstone assumes a greenish colour wherever oxide of tin is present. In addition to cassiterite this vein contains mispickel, topaz and emerald, and at various places in the district the alluvium is to some extent stanniferous.

Poullaouen and Huelgoët, situated near Morlaix, in the département of Finistère, were for a long time the most important lead mines in France, but have not been in active operation since the year 1866, and were abandoned in 1868. The workings, first commenced in 1729, were chiefly confined to two principal lodes, both of which traverse clay slates of Silurian age. The main lode

[1] *Géologie Appliquée*, 3rd ed. part i. p. 364.

at Poullaouen was opened for a length of 750 fathoms and to a depth of about 100 fathoms. Its width is very irregular, varying from a few inches to twenty-five fathoms. Its average breadth, which is somewhat difficult to determine, as it has neither selvages nor well-defined walls, may be taken at about six feet, while its course is nearly north-west and south-east with a dip of 45° to the north-east. The country rock, consisting of clay slate, associated with quartzite and greenstone, strikes east-north-east and west-south-west, and dips at an inclination varying from 40° to 50° towards the south. The principal ore is argentiferous galena, which is more or less mixed with blende and iron pyrites. These minerals, like the accompanying quartzose veinstone, form a network, in which the galena is more frequently associated with slate than it is with quartz. The strings or threads of mineral, which are often very narrow, sometimes expand to a width of several inches, and frequently separate to again re-unite. Granular ore is sometimes disseminated throughout the slate which forms a portion of the vein-material, and even the wall rock is in some cases similarly impregnated. This lode was considered rich when galena formed one-tenth of the vein-material. The galena is by no means equally distributed throughout the lode, but is found in courses of from 40 to 50 fathoms in length which incline at various angles in the direction of its strike. The ore contains from 0·0003 to 0·0005 of silver, or from 9 oz. 16 dwt. 0 gr. to 16 oz. 6 dwt. 16 gr. per ton.

The principal lode at Huelgoët, which is on the whole more regular than that of Poullaouen, but nevertheless varies in width from twenty inches to seventy-five feet, has been followed in length for a distance of 500 fathoms and to a depth of about 135 fathoms. Its average width may be taken at about twelve feet, its strike being north-west and south-east, with a dip of about 70° north-east. In addition to argentiferous galena this lode yields gossans, *terres rouges*, carrying a considerable amount of silver, both in the native state and as horn silver. These ochreous ores were mostly treated by amalgamation. The principal veinstone is quartz, which, in addition to galena, contains patches of pyrites, blende, pyromorphite, cerussite, plumbo-resinite, and laumonite. Blende and quartz frequently form ring ores, of which the centre is blende, and fragments of the wall rock are often in the same way encysted by an envelope of silica, as shown in Fig. 38, page 88.

For several years previous to 1857 the average annual yield of these mines was about 240 tons of litharge, 120 tons of soft lead, and 1,280 kilogr. of silver; the whole being of the estimated value of 480,000 francs, or £19,200.

At Pontpéan near Rennes, a lode yielding argentiferous galena and blende has been worked for a great many years; the vein is, according to M. Fuchs,[1] a fissure vein, enclosed in an ancient slate rock, running about N. 20° W.—S. 20° E. and practically vertical. The interior of the fissure contains the lead and zinc ores irregularly distributed, and there seems a probability that this vein was reopened subsequently to its formation, but that the new fissure was only filled with clayey matter, spoken of here as the "blue fault," within which are found fragments of ore broken from the vein itself. Its thickness is very variable, between half an inch and 28 feet, with an average of 8 feet. It has been worked to a depth of some 900 feet. This vein seems to be in some way connected with a dyke of igneous rock, apparently a diorite, which has broken through the Silurian schists at this point and which would seem to be older than the vein itself. The production of this mine has been :—

In 1880	lead ores	4,184	tonnes,	zinc ores	1,501	tonnes, total value	£43,388.
In 1890	,,	7,757	,,	,,	1,134	,, ,,	£58,330.

It also produced in 1890 2,629 tons of argentiferous iron pyrites, a mineral which was produced in but very small quantity ten years before. In 1894 its production was as follows:—

Argentiferous galena	16,136 tonnes	Total value £63,320.
Zinc blende	3,414 ,,	
Argentiferous pyrites	1,657 ,,	

According to the report of the Directors, issued April 30th, 1896, the production during 1895 was 119,310 tonnes of crude ore, which yielded on dressing a total weight of 30,502 tonnes of galena, zinc blende and pyrites, and 15,057 tonnes of galena containing 55 °/₀ of metallic lead, the total value of these products being about £68,470. The greatest depth attained in that year was 482½ metres.

There are likewise veins of galena, which were formerly worked near Saint-Brieuc, but, having gradually become impoverished in depth, they were abandoned in the year 1790, since which period some of them have been re-worked and again abandoned. The other veins of lead ore known to exist in this region are not sufficiently important to demand any special notice.

The Vosges.—The deposits of argentiferous galena of this

[1] *Rapport sur les Mines de Pontpéan* (*Rennes*), 1880.

region, which were wrought at a very early period, and yielded considerable returns of lead and silver during the course of the last century, are now almost entirely abandoned. Burat attributes this decay of the mining industry of the Vosges to bad management and a shortsighted policy on the part of former proprietors, and expresses his belief that had the same veins been situated in Saxony or the Harz, many of them would have continued in active operation down to the present day.

Numerous veins of argentiferous galena occur in the neighbourhood of Sainte-Marie-aux-Mines, the principal of which is known as the Lacroix Lode, and is celebrated for its great breadth of about sixty feet, as well as for having been worked upon for a length of more than two and a half miles. The lode of Lacroix-aux-Mines traverses the mountain of Saint-Jean at a distance of ten miles from Saint-Marie, has a north and south direction, and dips, nearly perpendicularly, parallel to the junction of the gneiss with a mass of syenite by which it is separated from the lodes of Sainte-Marie.

The lode is chiefly composed of *débris* of the surrounding rocks, in which the distribution of the ore is exceedingly variable. Sometimes it occurs in strings or branches, which occasionally unite to form a lode three feet in thickness, while at others it constitutes a sort of stockwork, or is disseminated in the form of patches or bunches. The ore chiefly consists of argentiferous galena, which is occasionally associated with other minerals, such as pyromorphite and pyrargyrite, native silver being also not unfrequently present. The average yield of the galena for silver is 32 oz. 13 dwt. 8 gr. per ton; and the works, which were carried on by means of an adit driven at the level of the natural drainage of the country, were never extended much below the adjoining valley. This vein is stated to have been at one period extremely productive, and large quantities of native silver were found in the upper levels. The production in the year 1756 is said to have been 1,200 tonnes of lead and 46,939 oz. of silver.

This lode was discovered in 1315, and in 1581 it was worked by the Duke of Lorraine with very profitable results; but the wars which took place towards the end of the century caused a suspension of the operations. In the year 1721 a lease of the mine was granted to a company which, after working it inefficiently during a period of eighteen years, again abandoned it. A new company re-opened it in 1755, but although they obtained considerable quantities of rich ore, they were unable to repair the damage resulting from the unskilful working of their predecessors.

In 1777 the ore was extracted without any proper regard to the support of the ground, so that the workings finally became crushed, and a company which commenced operations in 1785, and which during many years worked with intelligence and assiduity, was unable to put the mine into a satisfactory condition. The difficulties were subsequently increased by the revolution of 1789, and in the year 1808 the right to cut wood for fuel in the neighbouring forests, granted them by the Duke of Lorraine, was rescinded by Napoleon I. The mine was ultimately abandoned in 1816. A concession for Lacroix-aux-Mines was again granted in 1822, but all operations ceased in 1833, and they have not since been resumed.[1]

In the immediate vicinity of Saint-Marie-aux-Mines, the lead veins are smaller, and traverse the gneiss in an east and west direction. Two of these, namely, the Surlatte and the Espérance, have been worked upon for a considerable distance, but the galena contains only about one-half the proportion of silver which is present in that from the Lacroix vein.

At Giromagny, on the southern flank of the Vosges, is another group of metalliferous veins, which have from time to time been worked to more or less extent. These veins, of which the course is nearly north and south, are enclosed in porphyries and clay slates.

At Saint-Jean-d'Auxel there are three lodes which were formerly worked upon a somewhat extensive scale, some of the excavations being still open in 1779. Metalliferous veins are found almost always wherever porphyries and syenites are visible. At Plancher-les-Mines, at Fresse, and at Ternuay in the Haute-Saône, there are quartz veins which, in addition to calcite, and fluor spar, contain pyrites, gray copper ore, and argentiferous galena.

The metalliferous veins of the Vosges may be divided into two classes. The first, running nearly north and south, comprehends the principal lodes of argentiferous galena, while the second, coursing nearly east and west, includes, in addition to lead veins, a large number of quartz veins containing calcite, fluor spar, fahlerz, argentiferous galena, argentite, arsenical cobalt, native arsenic, and pyrites which is occasionally auriferous.

At Sainte-Marie-aux-Mines the Phaunoux vein, which was worked at the same time as the Surlatte and the Espérance lead lodes, yielded argentiferous gray copper ore with arsenical cobalt and native arsenic. The Phaunoux, Surlatte, and Espérance lodes belong to the class of which the direction is nearly east and west.

[1] H. Landrin, *Du Plomb, de son État dans la Nature, de son Exploitation, de sa Métallurgie et son Emploi dans les Arts*, Paris, 1857, p. 151.

The Selschaft, Saint-Martin, Sainte-Barbe, and Saint-Urbain at Giromagny yielded argentiferous gray copper ore with sulphide of silver and galena disseminated throughout the veinstone in such a way as to require stamping. At Saint-Daniel, on the other side of the Auxelle Mountain, the slimes resulting from the treatment of the ores contained copper, lead, and a considerable amount of silver. The mountains separating Giromagny from Plancher-les-Mines are traversed by numerous veins running in almost every direction, all of which contain ores of lead, copper, and silver.

In addition to veins yielding the metals above enumerated, the Vosges contain extensive deposits of iron ore. The most important of these is situated in the mountain of Framont, near the contact of a central mass of porphyry with the beds of schist and limestone, which it has uplifted and displaced. In this locality red hæmatite mixed with specular iron ore forms a contact vein of from fifteen to thirty feet in thickness surrounding the central mass of porphyry. The limestone, where it comes in contact with this ore, is either converted into crystalline marble or transformed into granular dolomite.

A large number of metalliferous deposits, in addition to those above enumerated, occur in various parts of the Vosges, but they are seldom of an extensive character, and with but few exceptions they are unworked.

Central France.—The plateau of Central France, which comprehends the mountains of Forez and Auvergne, as well as those of the Cévennes and Lozère, contains numerous veins of argentiferous galena, some of which are extensively worked and have yielded large quantities of lead and silver.

Pontgibaud, situated at the foot of a range of mountains four and a half miles north-west of Clermont, Puy-de-Dôme, and on the road from that town to Limoges, was for long the most important argentiferous lead mine in France although its productiveness has greatly diminished of recent years. The rocks traversed by the lead lodes in the vicinity of Pontgibaud are principally granite, gneiss, and schists, often broken through by dykes of porphyry, and frequently covered either by sheets of basalt, beds of cinder, or by flows of lava, from neighbouring extinct volcanoes. Two extensive lava-flows, issuing respectively from the Puy-de-Louchadière and the Puy-de-Dôme, unite near the smelting-works at Pontgibaud, and flow together for a considerable distance; while the River Sioule, which is in the immediate vicinity of the works, flows over a sheet of basalt, which on one of its banks is seen to be directly covered by a flow of lava. These volcanic phenomena, formerly so active, are now represented only by occasional mineral springs, and by an abundant evolution of carbonic acid gas, which occasionally presents a not inconsiderable obstacle to the working of some of the mines.

The veins, of which there are several, have a general direction of about N.E. and S.W. The veinstone of one only of these lodes consists chiefly of quartz, that of all the others being principally composed of a felspathic rock, differing but slightly from the enclosing granite and gneiss.

Near the surface the veinstone, as well as the enclosing rock, is usually more or less decomposed, but at greater depths they become gradually harder and less altered. The lodes frequently contain sulphate of barium, which is often well crystallised, but this mineral is only plentiful near the surface, and almost entirely dies out in depth. The quartz, which often accompanies the galena, is on the contrary more abundant in the lower levels than nearer the surface.

The felspathic quartzose rock, which constitutes the most abundant veinstone, usually contains less mica than the surrounding granite; but this is not invariably the case, particularly in large expansions of the veins, where the ore often appears disseminated in a somewhat decomposed granite. It is also to be remarked that the sterile parts of the lodes are usually better defined, and are more frequently separated from the country rock by clay selvages, than are the more metalliferous portions of the same vein.

The galena, which is always rich in silver, assumes various forms: sometimes it is extremely fine-grained like steel, at others it is lamellar, and less frequently it is found in the form of well defined crystals. The ore seldom forms bands parallel to the walls, but is usually disseminated through the veinstone either as small branches or as detached grains; the country rock likewise often contains branches and spots of galena.

The galena is often accompanied by a little blende or iron pyrites, and, less frequently, by patches of fahlerz. The mineral is chiefly found in shoots which, without having a large horizontal extension, hold downwards to considerable depths, while the intervals of unproductive ground are generally much longer than the courses of lead ore. There are also cross-courses, composed almost entirely of clay and seldom containing lead ores, which traverse and displace the metalliferous lodes.[1]

[1] Rivot and Zeppenfeld, *Annales des Mines*, xviii., 1850, p. 153.

Ancient workings, respecting the origin of which there are not even any traditions, afford evidence of the mines of Pontgibaud having been somewhat extensively wrought at a very early date.

A memoir by M. Guenyveau, published in 1822, furnishes some very interesting details relative to the history of early mining in the neighbourhood of Pontgibaud.[1]

The most ancient documents relative to these mines are letters patent granted 17th September, 1554, to the Seigneur de Lafayette, by Henry II., for working the mines of Combes, Roure, and Barbecot. In 1739 the working of these mines was undertaken by M. Dulude of Pontgibaud, and afterwards by the Chapades Company. In 1781 the works were recommenced by MM. Engelvin and Dulac, who formed an association called the Compagnie du Lyonnais. The operations were carried on until 1792, when the works were abandoned in consequence of political events which caused many members of the association to leave the country. From this time the mines remained unworked until 1826, when they were re-opened by M. de Pontgibaud under the direction of the celebrated M. Fournet, who was succeeded by M. Loupot, who remained in charge of the works until the year 1844. In 1836 the mines were purchased by a *Société en Commandite* bearing the title of Alphonse Pallu et Cie., who in 1852 transferred them to an English company, who entrusted the technical management to Messrs. John Taylor and Sons of London. Since that date the mines and smelting works have progressed steadily and satisfactorily, and have in the aggregate yielded large profits. They are now worked by the Société Anonyme des Mines et Fonderies de Pontgibaud of Paris, who also own mines at Couëron and Auzelles. Their greatest depth in 1883 was 110 and in 1891 about 130 fathoms, the workings being confined to the mines of Roure, St Denis, Mioche, La Brousse, and Pranal. According to the Directors' Report for 1895, their lowest workings had been at 820 feet, and at this depth the veins, although maintaining their full width and regularity of bearing, were everywhere found to be barren. It was therefore proposed to close down the mines, although it was also suggested that the mineral contents might make again at a greater depth.

The quantity of ore treated at the smelting works during the financial year 1879-80 amounted to 3,097 tonnes, of which 2,806 came from the mines of Pontgibaud, while the remaining 291 tonnes were purchased ores.

[1] *Annales des Mines*, vii. 1822, p. 161.

These ores yielded :—silver, 174,012 oz., value £41,359 ; lead 1,424 tonnes, value £21,469. The quantity of ore smelted and desilverised during the year 1880-81 was 2,902 tonnes, of which 2,717 tonnes were the produce of the Company's own mines, and 185 tonnes were purchased. In 1891 the mines produced 2,425 tonnes of ore valued at £20,600, and in 1894 the mines of the Pontgibaud Company in the Puy-de-Dôme produced 1,966 tonnes worth £9,600.

The production of the smelting works in 1880 was :—silver, 158,340 oz., value £39,952 ; lead, 1,044 tonnes, value £16,233. In 1894 it was :—silver, 8,590 kilogr., worth £37,890, and lead, 1,665 tonnes, worth £15,450. The ores were derived from other mines besides Pontgibaud.

The lead ores of Pontgibaud, although variable in this respect are always rich in silver, containing on the average above one ounce of that metal for each unit of lead present, so that 50 per cent. ores will contain above 50 oz. of silver per ton, and the lead flowing from the smelting furnace will always yield considerably above 100 oz. of silver per ton.

According to M. Lodin,[1] however, some of the mines show a marked decrease in the proportion of silver in depth ; this is best seen at la Brousse, where

Lead from ore at the surface contained	196	ozs. of silver per ton.
,, ,, between 40 and 60 mètres deep contained	163	,, ,,
,, ,, ,, 80 and 100 ,, ,,	131	,, ,,
,, ,, at about 180 mètres deep ,,	116	,, ,,
,, ,, ,, 240 ,, ,,	49	,, ,,

Two veins, St. Armand and Amatina at Pranal, gave at a depth of 70 mètres ⅗ and ¾ respectively of the richness in silver that they showed at the surface. In other veins in the district nothing of the kind can, however, be discovered. M. Lodin looks upon this surface enrichment as being due to the action of meteoric water (see p. 98) ; he points out that depth does not seem to have any definite relation to the richness of the ore, which is, however, decidedly determined by the more or less felspathic character of the granulite or microgranulite in which the veins occur. With respect to direction, the richest veins are found to vary from N. 12° W. (direction of la Brousse) to N. 45° E. (at Barbecot, Pranal, and Roure) ; between N. 45° E. to S. 45° E. practically no fissures occur, and those between S. 45° E. and S. 12° E. are barren. The veins

[1] "Études sur Pontgibaud," *Annales des Mines*, 9, i. 1892, p. 389.

follow the course of granite and granulite dykes, the fissures formed by these latter having been reopened subsequently and then the ore deposited; these dykes traverse gneiss and mica schist, and whenever the mineral veins pass from the eruptive into the metamorphic stratified rocks they are always barren.

It is, however, not quite clear why this rather complicated hypothesis of repeated fissuring need be invoked, especially as M. Lodin draws attention to the great density and impermeability of the stratified rocks, and points out that the richest portions of the veins are also in most cases those where the kaolinisation of the granulite has been most thorough. It would seem more likely that these granulite rocks, being the more permeable (possibly due in part to the contraction of their substance in cooling, which may have formed fissures and planes of weakness within them), mineralising solutions found their way into them, and metasomatically deposited the argentiferous lead ores within the areas thus rendered accessible to the solutions. The analogy between this latter view and the explanation now mostly adopted, of the genesis of the Comstock Lode, Nevada, is sufficiently obvious.

The mines of Vialas and Villefort are situated in the département of Lozère, but the veins of the first-named locality only are now worked. The granitic mass of Lozère is on all sides surrounded by mica schists, which gradually pass into clay slates, and constitute the true metalliferous rocks of the district. These schists are in some places covered by more recent rocks, such as the coal-measures of Grand Combe and Bességes, and occasionally by strata of Triassic, Liassic, and Oolitic age. All the veins which have been explored in these schists have been found to continue down into the granite, where they become contracted into mere strings of from half an inch to an inch in width, and which consequently do not admit of being advantageously worked. In many cases lodes which, at the surface, appeared only as narrow fissures containing little or no mineral, in depth produced considerable quantities of argentiferous galena, while, on the other hand, comparatively rich outcrops of lead ore have gradually dwindled and finally disappeared.

The different groups of veins and fissures found in the neighbourhood of Vialas are, in the following table, given in the order of their respective ages, as indicated by their intersections, the first-mentioned being the oldest:—[1]

[1] Rivot, "Sur les Filons de Galène Argentifère de Vialas," *Annales des Mines*, iv. 1863, p. 329.

Group.	Direction.	Group.	Direction.
1. Veins . . .	E. 11° N. True.	6. Veins . . .	N. 26° E. True.
2. ,, . . .	E. 33° N. ,,	7. ,, . . .	E. 18° N. ,,
3. ,, . . .	N. 41° E. ,,	8. ,, . . .	N. 40° W. ,,
4. ,, . . .	W. 20° N. ,,	9. Fissures .	N. 18° W. ,,
5. ,, . . .	S. 3° E. ,,	,, [1] .	S. 33° E. ,,

In addition to the above, considerable displacements of the country rock have taken place from east to west.

The veins of Group 1, which are not numerous but tolerably wide and well defined, dip towards the south at an angle varying from 75° to 80°.

Lodes belonging to Group 2 are the most important of those which occur in the vicinity of Vialas, comprehending as they do all the more productive metalliferous deposits of the district. They all dip to the south at angles varying from 60° to 80°, but it would be difficult to state, even approximately, their average width. The barren portions of these lodes are usually very narrow, while their richer parts are often without well-defined walls, as the ore either extends into the enclosing schists, or the lode is composed of a number of reticulated veins at varying distances apart.

The veins constituting Group 3 are not numerous, and are of but little importance excepting as regards their displacing other lodes; they dip towards the south at angles varying from 70° to 80°.

The veins of Group 4 are generally larger, and more distinctly defined, than any of the others; they are seen in all the schistose region surrounding the central mass of granite, and often appear as quartzose outcrops, standing forty-five feet above the surface of the ground, and may be followed for long distances.

Veins belonging to Group 5 are very numerous, and some of them have been well exposed in the various workings. They dip at an angle of 85° towards the west, and have smooth and well-defined walls. They vary in width from two to seven feet, and are usually composed of a carious quartz, which is generally white, but is sometimes stained brown by oxide of iron. These veins do not, as a rule, contain any ore excepting at their intersection with others, but in such situations deposits of galena rich in silver sometimes occur.

The veins belonging to Group 6 are numerous. They dip towards the south-east, and are composed of spongy ferruginous quartz. They have usually well-defined walls, which are sometimes

[1] The relative age of these fissures not being determined, it has not been thought desirable to assign them a number.

separated from the veinstone by a selvage of plastic clay of a dark colour.

Heavy spar forms the exclusive veinstone of Group 7, the veins of which dip towards the south.

The veins of Group 8 dip towards the south, are chiefly composed of comminuted schists, and are usually barren.

Group 9 is represented by a number of nearly vertical fissures, without slickensides, which divide all the veins of the preceding groups, and sometimes displace them for a distance of about a yard. Some fissures coursing S. 33° E. contain no filling of any kind, dip west at an angle of about 45°, and appear to be of no particular importance.

The period at which the mines of Vialas were first worked is somewhat uncertain, but that they were wrought at an early date is evident from the fact that some of the more ancient excavations bear evidence of having been made by the aid of fire. The more modern workings were commenced in 1781 upon some productive outcrops which about that time were accidentally discovered, and smelting works were established at Villefort for the treatment of the argentiferous galena produced in the immediate neighbourhood. In 1827 these mines were abandoned, and the works were removed to Vialas.

Between 1843 and 1877 the Vialas mines produced 7,000 tonnes of lead and 41,000 kilogr. of silver, the annual production of silver in these smelting works generally varying between 22,500 and 32,150 oz., but in 1856 reaching 48,225 oz. In 1861 and 1862 the yield was 61,278 oz. and 62,049 oz. respectively.

During the latter year the production of work lead was 367 tonnes; and 1,930 kilogr. of silver were obtained from 370 tonnes of lead. The work lead consequently contained 167 oz. of silver per tonne.

In 1880 the only mine besides Vialas working in the départe-ment of Lozère was Ispagnac, the yield of both during the year being returned at 577 tonnes of dressed argentiferous lead ore, of the estimated value of 177,667 francs or £7,106. In 1882 the output was 5,000 tonnes of ore containing 200 tonnes of lead and 1,000 kilogr. of silver, but since that time it has fallen rapidly; in 1891 it was only 203 tonnes of ore, and in 1894 it was only 116 tonnes, valued at £890.

Of recent years small amounts of antimony ore and manganese ore have been raised in this département; in 1894 there were 70 tonnes of the former produced.

Numerous metalliferous deposits occur in the valleys of the Aveyron and Tarn, in the neighbourhood of Villefranche and Milhau. These usually contain argentiferous galena, accompanied by calamine and by various ores of copper. The mines of this district were worked by the Romans, and in the tenth and sixteenth centuries are said to have yielded considerable amounts of silver, resulting in the establishment of mints for the coinage of that metal at Rodez and at Villefranche. These mines are stated to have been abandoned in consequence of the religious wars by which the country was devastated from 1560 to 1597. Working has recommenced in recent years but has been irregular; thus Tarn produced 400 tonnes of blende in 1891 but nothing in 1894. Aveyron has been working more steadily and produced in 1894 1,022 tonnes of argentiferous galena, valued at £11,800, and 3,258 tonnes of blende, valued at £7,265.

At Les Malines and Les Avenières (Gard) important deposits of zinc ores in veins and pockets in dolomite of lower Oolitic age have been worked since 1883. The pockets have probably been formed metasomatically whilst the veins may have been filled simultaneously. Les Malines produced about 4,000 tonnes of zinc ore in 1886, 23,000 in 1891, and in 1894 17,100 tonnes of calamine, 20,300 of blende, and 1,000 tonnes of galena, to a total value of £63,300.

The ancient copper mines of Chessy, situated in the département of the Rhone, ten miles north of Lyons, on the left bank of the River Azergue, are famous for having furnished the magnificent specimens of blue carbonate of copper, hence known as *chessylite*. Crystalline and metamorphic rocks here occur in immediate contact with Bunter Sandstone, which is overlain, with a steep south-easterly dip, by limestones of Liassic age. The more ancient rocks consist of granite, gneiss, mica schist, and aphanite, known to the miners as "hornstone," which predominates in the immediate neighbourhood of the metalliferous deposits. The general mode of occurrence of copper ores at Chessy will be understood on referring to Figs. 83, 84, after drawings by M. Raby, formerly manager of the mines.[1]

Four different kinds of copper ores were formerly obtained from this locality, namely, yellow copper ore mixed with iron pyrites containing from 15 to 20 per cent. of copper, known as *mine jaune;* melaconite intimately mixed with iron pyrites; yellow copper ore, silica, and various other substances, known as

[1] *Annales des Mines*, iv. 1833, p. 393.

mine grise or *mine noire;* cuprite, *mine rouge*, disseminated in the form of laminæ and crystals through a red clay; azurite or

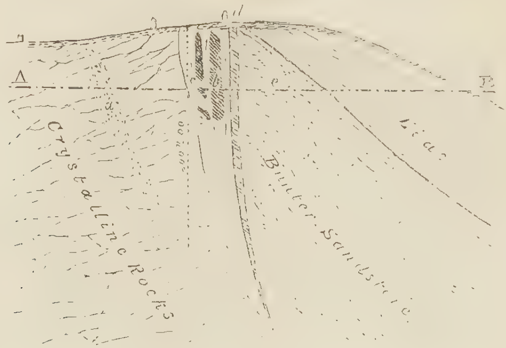


FIG. 83.—Copper ore deposit, Chessy; transverse section on C D, E, F.

blue carbonate of copper, *mine bleue*, found either in veins or disseminated in irregular concretions, and when crystallised containing about 70 per cent. of copper.

The *mine jaune*, consisting of mixed sulphides of iron and

FIG. 84.—Copper ore deposit, Chessy; horizontal section on A B.

copper, marked *a* Figs. 83, 84, was found only in the aphanite, where it formed one large mass which, commencing a few yards only below the surface, extended downward to a depth of 100 fathoms. This deposit was flattened in the direction of the bedding of the Mesozoic rocks, towards which it dipped at an angle of 66° with the horizon. Its greatest thickness, taken at a depth of sixty feet from the surface, was about forty-six feet, and its total length 100 fathoms. This mass of mineral was on all sides surrounded by more or less decomposed aphanite, from which it was not separated by any wall or selvage, the two materials being intimately mixed, and the one becoming gradually replaced by the other.

The *mine grise*, *b*, and *mine noire*, *c*, were found in the form of separate rounded masses enclosed in a wedge-shaped bed of grayish rock, which is interposed between the aphanite on the one side, and the sandstone on the other. The largest of these ore masses occurring in this rock, which has perhaps been produced by the decomposition of aphanite, had a length of 36 feet, a breadth of 9 feet, and a depth of 15 feet.

The *mine rouge* was found disseminated in a vertical bed of plastic clay of a reddish colour, *d*, where it was sometimes associated with a small quantity of native copper. This deposit commenced at the same level, and ceased at the same depth as that of the blue carbonates.

The carbonate of copper, *mine bleue*, represented in the woodcuts by the lines of shading, *e*, was found only in the beds of sandstone and in certain veins of clay with which they alternate. It usually occurred either in the forms of geodes lined with crystals, or in that of nearly solid masses having, in the majority of cases, a small cavity in their centre, but less frequently it was concentrated in veins parallel to the stratification of the sandstone. The largest of these veins had a horizontal length of 300 feet, a thickness of eighteen inches, and a depth along its underlie of about ninety feet.

With regard to the origin of these ores M. Raby remarks that all the copper found at Chessy was, without doubt, originally deposited in the state of *mine jaune*, and probably at the same time as the more ancient rocks. Some of the masses of this ore were subsequently converted by chemical action into *mine grise* or *mine noire*, while others were decomposed and by the re-arrangement of their elements gave rise to the formation of *mine rouge* and *mine leue*.

In the neighbourhood of Sain-Bel, a village six miles south-west of Chessy, situated on the Brevenne, a small river flowing towards the north-east, there were formerly copper mines somewhat similar to those once worked in the last-named locality. The granite in this district changes into gneiss, which soon disappears to give place to mica schist accompanied by clay slates and aphanite. The latter rock forms beds of very varying extent, some of which are, however, as much as ninety feet in thickness, and alternate with beds of mica schist or clay slate.

These, of which the strike is from north-east to south-west, are very nearly vertical, and associated with them is a parallel bed of a friable unctuous white schist, in which the whole of the copper occurred as thin veins of chalcopyrite following the direction of the planes of stratification. This formation extends for a considerable distance, but is, in many places, covered by rocks of more recent origin. The principal deposits formerly worked in the neighbourhood of Sain-Bel were those of Chevinay, Pylon, Sourcieux, and Gervais. Like those in the Chessy district, all these mines have long ceased to be wrought for copper. The only mining now being carried on in the district is for iron pyrites to be employed in the manufacture of sulphuric acid.

This now amounts to an important and rapidly growing industry in France, the total production of iron pyrites in the country being as follows in the years named:—

1880	132,300 tonnes,	value	£83,800
1883	165,200 ,,	,,	108,400
1886	184,900 ,,	,,	107,800
1889	201,500 ,,	,,	117,100
1893	231,000 ,,	,,	112,200
1894	283,400 ,,	,,	136,800

The Sain-Bel mines furnish by far the largest proportion of this output, from beds of mica schists impregnated with iron pyrites, a form of deposit referable to Group *d* of the class of Symphytic deposits, and from veins, of which three principal groups[1] are recognised in the northern, and two huge parallel veins in the southern portion of the district; these two latter veins have thicknesses that average ninety feet and fifteen feet respectively. These pyritic deposits are traceable for a length of some six miles. The Sain-Bel mines yielded 93,000 tons in 1880, and nearly the whole of the French output in 1893 and 1894 (278,000 tonnes in the latter year).

There are several deposits of pyrites in the département of Gard; one at St. Julien de Valgalgues, near Alais, is a contact

[1] Fuchs and De Launay, *Traité des Gîtes Minéraux et Métallifères*, p. 294.

deposit between Lias shales and Oolitic limestones; it seems to be of metasomatic origin as numerous Oolitic fossils wholly transformed into pyrites are met with in it. Its output in 1894 was 5,200 tonnes. In the département of Ardéche a pyrites deposit of a similar nature occurs at Soyons, but has not been worked recently.

Important deposits of manganese are worked at Romanéche (Saône-et-Loire); they consist of a series of true fissure veins, the most important of which fills a fault running north and south, and dipping 70° to the east. This fault unites two smaller veins running about north-east. Besides these veins there are some pockets, resembling somewhat the "flats" of the lead veins in the north of England, and which seem to be in part contact deposits, in part filling cavities in limestones of Liassic age. The ore consists of barytiferous psilomelane with about 60 to 70 per cent. of oxide of manganese and 13 per cent. of baryta.[1] The mines produced 10,870 tonnes in 1881, 9,500 tonnes in 1888, 8,780 in 1891, and 10,600 tonnes valued at £8,800 in 1894. Before 1891 about seven-eights of the French output of manganese came from these mines.

THE PYRENEES.—The Pyrenees abound in deposits of iron ore, which occurs both in the form of siderite and hæmatite; they do not, however, yield any large amount of the ores of the other metals, although mining for lead and copper was formerly carried on at various points.

The most important lead mines are those of Sentein, situated in the canton of Castillon, Ariége, at an elevation of 6,888 feet above the sea level, and worked by galleries driven on the course of the lode from the side of the mountain.[2]

The deposit is a contact lode, with Mountain Limestone as the foot wall and schist as the hanging wall. The direction of the mineral-bearing portion is N. 10° E., with a westerly inclination at an angle of about 60°. The lode consists of quartz, calcite, capel, &c., and the upper portion carries a gossan next the hanging wall, which contains rich deposits of carbonates, sulphates and sulphides of lead, together with blende and calamine. The lower portion is a strong lode of quartz, &c., containing galena mixed with blende.

The district at the base of the mountains, reaching to an elevation of from 3,280 to 3,936 feet above sea level, consists of schist. This is covered by limestone varying from 164 feet to

[1] Fuchs and de Launay, *op. cit.*, ii. p. 15.

[2] I am indebted to Mr. Ernest du B. Lukis, of St. Fiacre, for the information relative to the Sentein Mines—[J.A.P.].

several hundred feet in thickness, above which is an irregular layer of schist. The ore-bearing lode, which occurs between the schist and the limestone, may be traced for a great distance along the ridge of the mountains following the horseshoe curves of the strata. Above the schist is another limestone which, with quartz, forms the peaks of the mountain. This quartz does not contain gold, although the galena sometimes gives as much as 3 dwt. of fine gold per ton.

The lowest strata of schist contain poor lodes of copper pyrites and some carbonate of copper, with bands of ironstone. Hæmatite and deposits of blende are met with near the summit of the range, but are not workable.

The galena, enriched by mechanical means to 78 per cent. of metallic lead, gives 580 grammes of silver or about 18½ oz. per tonne. The carbonate of lead, at 72 per cent. of metallic lead, but containing a little sulphide, yields 800 grammes of silver per tonne. Very little silver is lost during the mechanical treatment of these ores. The blende contains no silver.

The annual production of the mines varies very much, owing to the inclemency of the weather at the altitude at which they are situated. In 1882 there were sent to the dressing floors about 11,500 tonnes of crude ore, giving about 850 tonnes of marketable lead ore and about 1,100 tonnes of marketable blende. In 1891 the Sentein mines produced 1,626 tonnes of blende and calamine, and together with the near mine of Minconstans 592 tonnes of argentiferous galena. In 1894, however, there was practically no production at all.

About ten miles from Aulus, Ariége, may be observed remains of some ancient excavations, together with outcrops of metalliferous deposits containing iron pyrites with traces of argentiferous galena and blende, but consisting principally of calcite and fluor spar. This mine, which is known as the Argentière, has been repeatedly worked at various periods, but has now been abandoned for many years. Among the ancient mines sometimes spoken of in this part of France are those of Baigorry, Basses-Pyrénées, which formerly yielded a small quantity of copper.

Numerous deposits of iron ores and of other metalliferous minerals occur in the Pyrenees, but they are generally of limited dimensions and are, for the most part, unworked.

The mines of Las Cabesses[1] near St. Girons are now the most

[1] From *L'Echo des Mines et de la Métallurgie* and private communications from the Managing Director.

important producers of manganese in France, their output being over one half of that of the entire country. The deposits consist of beds of carbonate of manganese superficially changed in places into black oxide. The thickness of the main bed is about 70 metres, but the dimensions of the deposit have not yet been proved, though they seem to be considerable. The ore now raised is almost all carbonate, containing 40 to 45 per cent. of metallic manganese, some 6 per cent. of silica, and only 0·03 to 0·04 of phosphorus. A good deal of the ore is calcined at the mines, by which means the percentage of manganese is brought up to 55 per cent.; at present about one-half of the mineral is sold raw and one-half calcined. These mines promise to yield very large quantities of ore when fully opened up. Their development dates from 1890, and their production has been as follows:—

1890 . . .	about	3,000	tonnes of raw ore.
1891 . . .	„	12,000	„
1892 . . .	„	22,000	„
1893 . . .	„	24,000	„
1894 . . .	„	25,000	„

According to the official returns,[1] the production in 1894 was 7,866 tonnes of picked mineral and 10,895 of calcined (equal to 16,760 tonnes of raw ore), worth together about £28,200.

The Alps.—Numerous deposits of iron ore are worked in the French Alps, but mining for the ores of other metals is not carried on upon a large scale.

The small but well-cultivated plain which lies below Bourg D'Oisans, Isère, is traversed from south-east to north-west by the River Romanche, and from east to west by the Olle, one of its tributaries. Immediately north of the confluence of these two streams the mountains of Chalanches, a spur of the Alpine chain, rise to a height of 6,700 feet above the plain, or about 9,000 feet above the level of the sea. The upper portion of this range is composed of a gneiss in which felspar and hornblende are always abundant, although quartz and calcite are sometimes also plentiful, while epidote, chlorite, talc and mica are by no means uncommon. This rock, although occasionally fine-grained, more frequently exhibits a coarse porphyritic structure, but in the vicinity of veins the felspar and hornblende, which are elsewhere present in a crystalline form, often graduate imperceptibly into the surrounding ground-mass. The beds present considerable undulations, but their

[1] *Statistique de l'Industrie minérale pour l'année* 1894, p. 55.

general strike is nearly north and south with a dip towards the west. Near Allemont, on the east, the gneiss is overlain by hornblendic schists.

The discovery in the year 1767 of native silver in this locality by a goatherd whilst in search of a strayed kid, resulted in mining operations which ultimately extended from a height of 4,100 feet to 4,970 feet above the level of the plain, and necessitated the erection of store-houses and dwellings upon the mountain side.

Among the principal lodes which have been, at various times. worked at Chalanches are the following :—[1]

The Freiddan,	bearing	25° S. of E., N. of W.,	and dipping	S.W.
,, Cobalt	,,	30° W. of N., E. of S.	,,	N.E.
,, Siméon	,,	35° W. of N., E. of S.	,,	N.W.
,, Prince	,,	20° W. of N., E. of S.	,,	E.
		20° N. of E., S. of W.	,,	N.
,, Hercule	,,	20° W. of N., E. of S.	,,	E.
,, Pirou	,,	25° E. of N., W. of S.	,,	S.E. and N.W.
,, Ste. Hélène	,,	20° W. of N., E. of S.	,,	W.

Although these lodes generally measure but a few inches, and average less than a foot in width, they sometimes, for short distances, assume a thickness of as much as 2½ feet. The veinstone very closely resembles the enclosing rock, consisting of the same materials although in different proportions, but containing, in addition, some other minerals. Quartz and calcite are always present, hornblende is perhaps somewhat less plentiful, while chlorite, talc, mica, asbestos and epidote are found only occasionally, and in comparatively small quantities.

Calcite, chlorite, asbestos and epidote are often associated with silver ores, but earthy brown iron ore more frequently accompanies the richer metalliferous deposits. The produce of these veins principally consists of native silver, antimonial silver, freieslebenite, stephanite, pyrargyrite, and occasionally a little horn silver. These minerals are often accompanied by ores of cobalt or nickel, or by both, and various ores of antimony, lead and copper are likewise thinly disseminated through the veinstone. The Brisée Vein is a cross-course which differs less in direction from some of the lodes than, in this respect, they differ from one another. It dips at a higher angle than any of the veins in its vicinity, and is wider than the widest lode in the district. It consists wholly of gneiss, and intersects the Hercule Lode, displacing it about twelve fathoms towards the right.

[1] W. J. Henwood, *Trans. Geo. Soc. Cornwall*, viii. part i. 1871, p. 520.

In the hornblendic schists which succeed the gneiss near Allemont on the south-east, an unsuccessful trial was made on a vein bearing E. 35° N. and dipping towards the west. This measures about eighteen inches in width, and is composed of disintegrated slate and quartz, which is spotted with black oxide of manganese and specular iron ore.

These mines were worked at so great an elevation and at such a distance from every habitation that, even in summer time, the workmen seldom visited their families except on Sundays, and during many of the winter months all communication with their nearest neighbours was entirely cut off by frozen snow-drifts many miles in extent. In spring the steep and ill-made roads were always found to have been rendered almost impassable by avalanches and the general thaw, so that it was necessary to collect at the mines during the summer all materials, tools, food, fuel, and other requisites, for the winter. With the view of reducing to a minimum the cost of carriage, every tool and utensil was shaped upon the plain below, which materially added to the ordinary expenses of working.

The mines of Chalanches have been wrought at various periods, and the ores raised were smelted at Allemont. From 1767 to 1776 they were worked on account of the Government; from 1776 to 1792 by the Comte de Provence, afterwards Louis XVIII., and from 1792 to 1808 again on account of the Government. All subsequent workings which have been undertaken by various lessees have, without exception, resulted unsatisfactorily.

From 1767 to 1803 the quantity of silver extracted amounted to 25,326 lbs. troy, of the value of £83,939, while the general expenditure was £75,636. The net profit realised in thirty-six years was therefore £8,303, equivalent to an average profit of about £230 12s. 9d. per annum.

The mine of Cerésier, Alpes-Maritimes, worked by the Société des Mines du Var, produced in 1882 a larger amount of copper ore than any other in France. In the year 1880 the production amounted to 8,000 tonnes of an ore containing about four per cent. of copper in the form of chalcocite. Of this amount, 5,000 tonnes were concentrated as a preliminary to being treated by a process for the extraction of copper by lixiviation. There are important mines of zinc at Les Bormettes (Var), which also produce a certain amount of galena; they produced 1,730 tonnes of blende in 1885 7,430 tonnes in 1888, 20,200 tonnes in 1891 and 24,000 tonnes of blende and 1,500 tonnes of galena, worth together £53,600, in 1894.

Excepting the ores of iron, the amount of which has been already stated (p. 330), the production[1] of metalliferous minerals during the years 1880 and 1894 was as follows :—

Production in France of Metalliferous Minerals other than Iron Ores during the years 1880 and 1894.

	1880.		1894.	
	Weight.	Value.	Weight.	Value.
	Tonnes.	£	Tonnes.	£
Lead and Silver ore .	13,990	129,175	29,055	94,784
Copper ore	8,649	5,977	—	—
Zinc ore	12,139	15,417	80,065	165,172
Manganese ore . . .	9,652	21,309	32,751	40,052
Antimony ore . . .	1,214	9,737	6,144	16,244
Iron pyrites	132,288	83,812	283,439	136,980
Totals	177,932	265,427	431,454	453,232

BELGIUM.

Taking into account its limited area, Belgium is, in respect of its mineral wealth, one of the most productive countries of the world. Coal, iron, lead and zinc ores constitute its chief mineral resources, but, in addition to these, it furnishes numerous valuable mineral substances employed either as building material, for agricultural purposes, or in the arts and manufactures.

Iron.—The iron ores worked in Belgium are hæmatite, limonite, and clay ironstone. The latter is sometimes associated with limonite, but also occurs in independent deposits, which are, however, usually too small to admit of being worked with advantage.

Hæmatite occurs in various conditions and on very different geological horizons, but that which is almost exclusively employed is in the form of oolitic or pisolitic grains. In this state it forms important deposits in quartzose schists which underlie the coal-measures, and crop out on both sides of the valley containing the coal. The principal iron mines are situated on the north side of the valley where, in the neighbourhood of Vedrin, there are four distinct seams of ore, respectively $2\frac{3}{4}$ inches, 4 inches, 8 inches, and $11\frac{1}{2}$ inches in thickness, forming with the intercalated schists a bed nearly four feet thick.

At Marchovelette there are five strata of iron ore varying in

[1] *Statistique de l'Industrie minérale pour l'année* 1894.

thickness from 4 to 8 inches; while at Ville-en-Waret there are four beds, two of which vary from 8 to 20 inches in thickness, which with the interstratified schists form a group of about twenty-four feet. At Houssois, near Vezin, the hæmatite attains a thickness of about seven feet. The beds of hæmatite are, at various points, intersected by veins and faults, in the vicinity of which both the ore, as well as the enclosing schists, are not unfrequently impregnated with pyrites, galena and other metallic sulphides, by which the quality of the former is more or less impaired. The workings along the outcrop on the south side of the valley, are much less important than those on the north. The principal mines are near Huy, where there are two layers of hæmatite having a united thickness of little less than four feet, separated by about one foot of shale. The average yield of these hæmatites is from 35 to 40 per cent. of metal.

Limonite occurs in various forms, and in deposits of very different geological age. In the more recent formations it is found in beds, sometimes above three feet in thickness, reposing in depressions in argillaceous sands mainly situated along the banks of the rivers Demer, the two Nethes, and their affluents. The ores from these deposits, which are concretionary and porous, contain about 40 per cent. of iron, with a considerable amount of phosphorus, but they are easily reduced. A siliceous limonite, containing phosphorus, is worked in a Quaternary formation near Quévy, in the province of Hainault. This ore, associated with an argillaceous sand, forms a bed from 3 to 5 feet in thickness, enclosed in a depression in Tertiary sandstone.

The isolated and superficial deposits of iron ore which occur in the province of Luxembourg, and notably at Ruette, Athus, Tœnich, &c., likewise belong to the Quaternary age, and repose upon Jurassic rocks. These ores have apparently resulted from the disintegration of Jurassic rocks during the Quaternary period, and contain from 30 to 45 per cent. of iron.

The Jurassic formation constituting the surface of the southern portion of the Belgian province of Luxembourg, as well as the Grand Duchy of that name and the northern part of Lorraine, is exceedingly rich in iron ore identical with that of the Meurthe-et-Moselle (*see* page 327), and furnishes important supplies to the Belgian ironworks. The ore from these localities is known by the name of *minette*, and is a fine-grained oolitic limonite which occurs in extensive deposits in Luxembourg and Lorraine, but less plentifully in Belgium. Near the French frontier the beds of this ore are from 5 to 6 feet in thickness, and the ore contains from 30 to 45 per cent. of iron. The gangue consists principally of calcite, with a little silica and gypsum.

The rocks comprised between the lower quartzose schists and the coal formation, enclose many important deposits of limonite which, up to the present time, have furnished the larger portion of the ore consumed in the Belgian ironworks. These deposits are often very extensive, and the ore always occurs either in masses or veins, but never in the form of beds. The largest production of iron ores in Belgium was in 1865, when it amounted to 1,018,231 tonnes. In 1875 it was only 365,044 tonnes, and in 1881 it was further reduced to 224,828 tonnes, dropping to 152,600 tonnes in 1886, from which point it gradually recovered, till it was again 311,000 tonnes in 1894.

Deposits of manganiferous iron ores, suitable for spiegel making, have been worked in the valley of the Lienne, province of Liége, for some years, but their production was quite insignificant till in the year 1887 a branch railway to the district was opened, when the output at once sprang up suddenly to respectable dimensions. The development of this mineral district is shown in the following table :—

Output of Manganiferous Iron Ore.

Year.	Quantity.	Value.	
	Tonnes.	francs.	£
1881	770	3,850	154
1882	345	1,750	70
1883	820	4,100	164
1884	750	3,750	150
1885	—	—	—
1886	750	9,000	360
1887	12,750	156,000	6,240
1888	27,787	325,000	13,000
1889	20,905	248,000	9,920
1890	14,255	176,000	7,040
1891	18,498	254,600	10,184
1892	16,775	208,300	8,332
1893	16,820	209,500	8,380
1894	22,048	277,700	11,108

Lead and Zinc.—Lead ores occur in Belgium in the older formations only, where they are found in veins and masses, either alone or associated with blende and pyrites. The veinstone usually consists of calcite, heavy spar and quartz, together with clay and limonite; in massive deposits the gangue is generally a dark clay. Galena, which is found in numerous places, many of which are not of sufficient importance to pay the expenses of working, is frequently accompanied by other ores of lead, such as cerussite and pyromorphite; it is also often associated with blende and calamine.

The most productive lead mine of Belgium is that of Bleyberg, near Moresnet, which is worked upon the only vein in the country, which, after having traversed the Carboniferous Limestone, penetrates the Coal-measures. Considerable masses of lead ore are found along the line of contact of these two formations, but they are worked with difficulty on account of the very large influx of water.

The most important zinc ore of Belgium is zinc carbonate, commonly known as calamine. The hydrous silicate is of less frequent occurrence, as is likewise the anhydrous silicate of zinc, or willemite. Blende is almost constantly found in association with the other ores of zinc, but, as its metallurgical treatment is more expensive, its value is proportionately less. The ores of zinc, like those of lead, are found in the older formations only, and usually occur either in Carboniferous Limestone, or in rocks of Devonian age, where they form lodes and irregular deposits, associated with galena and iron pyrites. These massive deposits are sometimes several hundred yards across, and the ores in them have usually a gangue of clay, sometimes, however, replaced by limonite, which is occasionally worked as an ore of iron.[1]

The Bleyberg lead vein[2] is enclosed in the Carboniferous Limestone, and in the Coal-measures overlying it. The general direction of the lode is north-west and south-east, forming with the true north an angle of 57°, and with the stratification one of about 115°. It can be recognised for a distance of 3 miles in the Coal-measures, and above 1¼ miles in the limestone. This vein is either vertical, or dips at an angle of from 75° to 80° with the horizon, sometimes to the east and sometimes to the west. No fault or cross-course is known to exist, but it is believed that a change of direction towards the north may have been caused either by a heave or by a bifurcation of the vein.

The filling of the lode, when enclosed in the Coal-measures, is,

[1] Much information relative to the mineral resources of Belgium has been derived from Mr. J. D. Hague's report on *Mining Industries in Connection with the Paris Exhibition*, 1878, Washington, 1880.—J. A. P.

[2] See pamphlet published by the Bleyberg-es-Montzen Company during the Exhibition of 1878. *Extrait du Catalogue de l'Exposition de l'Industrie minérale belge.*

to a large extent, made up of the *debris* of schists, sandstones, and grits, which having fallen into the fissure, have partially filled it. When the vein traverses rocks liable to crumble or disintegrate, these fragments are invariably most abundant; but, when the country rock is hard and compact, they are less numerous and leave larger spaces to become filled in another way.

During the time this partial filling of the opening with country rock was actually taking place, or some time subsequently, the fissure and its contents have been subjected to the action of waters containing, in solution, various metalliferous substances, and these have been deposited in the cavities existing between the fragments of the material already partially filling the vein cavity. In this way the filling of the fissure has been partly mechanical, occasioned by the falling in of the sides, and partly chemical, produced by the deposition of minerals from waters holding them in solution. No eruptive rocks have been met with in the district under consideration. The veinstone frequently exhibits a concretionary structure, and where the rocks are hard, and the spaces between the fragments necessarily large, the metalliferous minerals are deposited in ribbon-like bands. These deposits of mineral are composed of alternate layers of blende and galena, the two being but seldom mixed. Alternate layers of this kind have been frequently repeated, the blende having evidently been the first mineral deposited. The galena carries small quantities of copper, antimony, and silver, with traces of other metals.

Ribboned deposits of blende and galena have been unable to form in those parts of the vein where the whole of the fissure had been already filled with pieces of the country rock, but, in the majority of cases, these fragments have left between them spaces of greater or less dimensions. In such places the blende and galena have taken the exact shape of the cavities left, and have surrounded the fragments of country rock, so as not only to preserve their form but also their sharpness of outline. For considerable distances on the length of the fissure, the filling of schist has been so completely disintegrated that it has become filled with unctuous clay, which, being almost completely impermeable by water, has caused certain portions to be nearly absolutely barren. In these portions of the lode blende and galena are sparingly disseminated in the form of minute grains with a few occasional geodes, and with, occasionally, a few crystals of various minerals, in strings and cracks. At Bleyberg the influence of the country rock appears to be limited to the effect produced by the amount of material falling into the fissure, and the space consequently left open for the circulation of mineral waters, and for the deposit of ores.

The waters have not introduced into the Bleyberg Lode a sufficient amount of metalliferous material to fill all the cavities remaining open, and these have subsequently been closed by deposits of calcite and silica, removed from the surrounding limestones and schists by the agency of waters impregnated with carbonic acid. Ferruginous minerals have been introduced into the lode in a similar way, and iron pyrites is not unfrequently met with in a compact or cavernous form, in that of stalactites, or as thin strata in geodes, often lined with crystals of blende, galena, or calcite.

In studying the genesis of this lode another phenomenon must not be lost sight of, and that is, that during the progress of the deposition of these minerals, or perhaps afterwards, the vein fissure was several times re-opened. These re-openings of the vein have imparted to the mass movements which not only led to a partial re-arrangement of its contents, but likewise resulted in certain physical effects. In this way there has been a sinking of one or other of the walls of the lode, or a depression or elevation of its filling, giving rise to slickensides and vertical striations of the surfaces. In this way also the regularly foliated deposits of ore have become displaced, turned over, and mixed with those of an irregular and fragmentary nature. Finally, at one period of its formation, the vein fissure, while opening at one side, was gradually closing on the other, which at such points resulted in the crushing of its filling, and its reduction to the state of angular fragments. When the re-opening of a vein fissure occurs during the percolation or passage through it of mineral waters, deposits will take place upon the surfaces of the fragments resulting from crushing, and it is not uncommon to find in the Bleyberg Vein a deposit of perfect crystals upon broken crystals of the same or of some other mineral. The metalliferous portion of the lode, together with the various associated minerals constituting its filling, has an average width of nearly three feet; but the enclosing Coal-measures exhibit the effects of the disturbing influences of the rent for a width of above thirty-six feet, within which limits the country rock is crushed and, to some extent, displaced.

The deposits of substances introduced by the mineral waters before referred to, sometimes occupy one side of this broken ground, and sometimes the other; but their passage can always be traced by the metalliferous, calcareous, or siliceous materials which fill its fissures. On either side of this disturbed zone the rock remains entirely unchanged, and is without any trace of extraneous minerals, even along its planes of stratification.

In the Carboniferous Limestone the filling of country rock resulting from the disintegration of the walls, no longer consists of schists, sandstones, and grit, but is almost entirely composed of limestone with some blende and galena. The ores here found are precisely identical in composition with those occurring in the Coal-measures ; they crystallise in the same dominant forms, and contain similar proportions of copper, antimony, and silver. In the upper part of the limestone there are found, without any recognised order, carbonates of lead, zinc, and copper, which usually enclose kernels composed of the sulphides of the same metals.

The phenomena of the re-openings of the fissure, of the mixing of its filling, and of the crushing by its walls of the veinstone, are seen even more distinctly in the upper portions of the limestone than they are in the Coal-measures. At this point the limestone above the fracture has been eroded into an opening above 1,600 feet in length, 180 in width, and from 180 to 250 in depth.

On the walls of this cavernous space, and on the surfaces of a material representing geyserite, large quantities of blende and galena were at some time deposited, but by subsequent violent shocks they have become detached and mixed with various other bodies, including fragments of some of the older rocks. Nothing can be more instructive or interesting than these accumulations, in which, although all the minerals and gangues occur in the form of fragments, each individual piece, either by its banded structure or by the arrangement of its crystals, bears distinct evidence of once having formed part of a regular deposit. On the eastern wall of the cavern deposits of blende, galena, calcite, &c., are sometimes found *in situ*, and still adhering to the rock, just as they were left by the waters through the agency of which they were deposited.

A large mass, principally of galena, also occcurs at the junction of the Coal-measures with the Carboniferous Limestone, at which point it would appear there was formerly a lake-like depression supplied with plumbiferous waters. In this way was probably produced a large deposit of lead ore, in all respects identical in composition with that obtained from the lode, although forming a solid mass and entirely without any admixture of fragmentary country rock. This mass which rests upon a somewhat extensive base of the Coal-measure formation, has never been disturbed as in the case of the lode, in which the crushing and mixing of the ores has resulted from the repeated re-opening of the fissure and the consequent movements of its walls. This deposit comes to within twenty yards of the present surface, and is covered by detrital matter from the Coal-measures, and by various shales and rocks of Tertiary age, all stratified horizontally, but unconformably, with the Coal-measures and sandstones.

The amount of water percolating into the Bleyberg mines is unusually large, generally amounting to 7,260 gallons per minute, but, exceptionally, reaching 12,000 gallons per minute, which is pumped from a depth of 597 feet. From the date of the formation of the present Company, 1853, up to May 1878, this mine had produced 86,850 tonnes of zinc ores and 86,876 tonnes of lead ores, during which time it had repaid its capital four times over. Since 1890 its production has been insignificant.

The important deposit of calamine at Vieille-Montagne, Altenberg or Kelmisberg, belongs to the Vieille-Montagne Company, and is situated near Aix-la-Chapelle, in the immediate vicinity of the village of Moresnet. It occurs in the lower strata of the Carboniferous Limestone, which are, for the most part, converted into dolomite, and fills a basin-like depression, of which the longer axis has a length of 600 yards, while its width varies from 200 to 260 yards. This basin of zinc ore and dolomite is, on one side, raised towards the surface and, on the other, dips beneath it, being itself enclosed in soft Devonian schists which come to the surface on both sides. A bed of quartzose dolomite, which carries large quantities of water, separates the two rocks, and in all directions bounds the deposit with great regularity. The ore, which towards the surface is principally composed of very pure calamine with scarcely any admixture of blende or galena, has nearly filled the tilted basin before referred to, and crops out at the surface for a considerable distance.

At Kelmisberg the zinc ore being entirely surrounded by dolomite, nowhere comes into contact with other rocks, and can scarcely be regarded otherwise than as resulting from the gradual transformation of the enclosing dolomite into zinc ore by an exchange of bases effected through the agency of metalliferous waters. This remarkable deposit of ore was most extensively developed near the surface, where it reached a length of 490 yards and a width of 180 yards.

The most productive and most highly concentrated portion of the deposit is situated at the northern extremity of the basin, and is separated from the southern body of ore by a projecting point of dolomite. Towards the south-west the deposit is continuous, but is hidden under a capping of dolomite beneath which it has been followed to a depth of 120 yards. While, at the surface, the ore consisted chiefly of carbonate of zinc, lower down it became mixed with hydrated silicate of zinc, which gradually increased in quantity until it eventually formed the larger portion of the ore. Anhydrous silicate of zinc, willemite, has always been found in large masses scattered without any apparent rule throughout the other ores.

The first shafts are said to have been sunk during the fifteenth century for the purpose of supplying calamine to the foundries of Aix-la-Chapelle, the proprietors of which, without any knowledge of the metal it contained, employed it in the manufacture of brass. The largest yield was in 1855, when it reached 137,000 tonnes of ore as it came from the mine, or 50,900 tonnes of concentrated ore. Since the year 1856, the workings have been carried on under ground, and it is known that up to 1878 about a million and half tonnes of first class ore had been extracted from these deposits, which were practically exhausted by 1882. The almost chemically pure zinc, which is employed for making *blanc de neige* and for art-castings, is exclusively made at the Moresnet works.

The bed of zinc ore at Welkenrädt[1] occurs between coal-shale and Carboniferous Limestone, extending for a distance of more than 120 fathoms along the strike. It dips, like the adjacent beds, at a very high angle, and, with them, has undergone the same folding and faulting. The foot wall, which is in contact with the limestone, consists of either compact, drusy, foliated, shaly, or earthy hydrous silicate of zinc, which, in the higher levels, becomes ferruginous and passes into ironstone, or into a shaly mass with enclosures of limonite. The hanging wall, in contact with the shale, consists of a black clay, which contains nodules and fragments of various metallic sulphides, such as concentric blende, galena, and pyrites. The sulphide-bearing zone which is of much greater extent than that producing zinc ores, is known as the foot wall of the Coal-measures, and is justly regarded as an interstratified deposit. In Fig. 85, after Braun which represents this deposit, *a* is limestone, *b* shale, *c* clay containing ironstone, *d* shale with galena, &c., and *e* hydrated silicate of zinc.

All these are irregular deposits of apparently metasomatic origin and must be classed among the ore masses occurring in or with calcareous rocks.

The production of metalliferous minerals in Belgium has for

[1] M. Braun, *Zeitschr. d. d. Gesellsch.*, ix. 1857, p. 354.

some years been gradually decreasing, although their importation into that country for metallurgical treatment is very large. This decrease of yield appears to affect almost equally all the ores

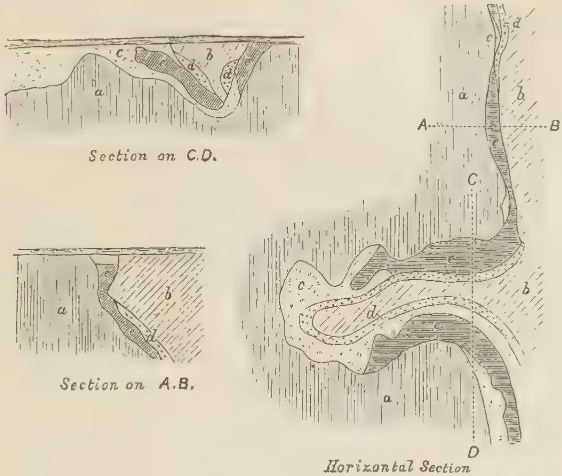


FIG. 85.—Deposit of silicate of zinc; Welkenrädt.

produced. This declining tendency of metalliferous mining in the country is clearly shown by the following table, which gives the production by decades :—[1]

Period.	Zinc Ore.		Lead Ore.		Iron Pyrites.		Iron Ore.[2]		Total Values.	
	Quantities.	Values.	Quantities.	Values.	Quantities.	Values.	Quantities.	Values.		
	Tonnes	Francs.	Tonnes	Francs.	Tonnes	Francs.	Tonnes	Francs.	Francs.	£
1841—1850	373,503	18,437,000	23,034	3,387,000	31,108	347,000	3,437,940	30,521,000	52,962,000	2,318,480
1851—1860	770,887	37,522,000	72,814	9,880,000	200,090	3,487,000	7,118,869	68,886,000	119,783,000	4,791,320
1861—1870	638,459	30,426,000	140,964	23,478,000	391,134	8,548,000	7,853,159	75,660,000	138,112,000	5,524,480
1871—1880	454,548	27,219,000	108,433	17,436,000	274,480	6,547,000	4,271,831	39,956,000	91,158,000	3,646,320
1881—1890	211,577	9,662,000	14,101	2,264,000	32,565	363,000	1,955,325	13,660,000	25,949,000	1,037,960

The table on the following page from official sources[3] will probably prove of interest in the same connection :—

[1] Em. Harzé, "Statistique des mines, etc., en Belgique," *Bull. de la Soc. de l'Industrie Minérale*, 3, vi. 1892, p. 931.

[2] The quantities and values of manganiferous iron ores tabulated on p. 354, are included under this head.

[3] Royaume de Belgique, Ministère des Travaux Publics, *Compte Rendu des Opérations Pendant l'Année* 1881, "Mines," p. 5, Bruxelles, 1882; *Statistique des Mines, Minières, Carrières, etc.*

TABLE SHOWING THE PRODUCTION OF METALLIFEROUS MINERALS IN BELGIUM DURING TWENTY-THREE YEARS FROM 1871.

Years.	Zinc Ore.		Lead Ore.		Iron Pyrites.		Iron Ore.[1]		Total Values.	
	Quantities.	Values.	Quantities.	Values.	Quantities.	Values.	Quantities.	Values.		
	Tonnes.	Francs.	Tonnes.	Francs.	Tonnes.	Francs.	Tonnes.	Francs.	Francs.	£
1872	55,177	3,766,000	11,887	1,936,000	40,932	985,000	749,781	7,390,000	14,077,000	563,080
1873	42,582	3,014,000	11,280	2,183,000	36,651	1,060,000	777,469	7,834,000	14,091,000	563,640
1874	43,299	2,707,000	10,894	2,194,000	28,872	778,000	527,300	5,178,000	10,857,000	434,280
1875	42,504	2,878,000	10,567	2,005,000	30,747	807,000	365,044	3,423,000	9,113,000	364,520
1876	37,713	2,555,000	12,422	1,702,000	23,588	566,000	269,206	2,458,000	7,281,000	291,240
1877	44,987	2,505,000	11,542	1,919,000	26,207	639,000	234,227	2,158,000	7,221,000	288,840
1878	45,293	2,479,000	13,477	1,548,000	21,721	523,000	207,157	1,758,000	6,308,000	252,320
1879	42,689	2,145,000	9,384	1,087,000	15,577	324,000	195,212	1,567,000	5,123,000	204,920
1880	38,805	2,242,000	5,434	892,000	7,913	164,000	253,499	1,875.000	5,173,000	206,920
1881	23,553	1,195,000	3,741	657,000	2,965	49,000	224,882	1,817,000	3,718,000	148,720
1882	20,443	707,000	2,918	486,000	2,555	21,000	209,212	1,593,000	2,807,000	112,280
1883	20,738	750,000	1,749	311,000	1,623	18,000	216,490	1,497,000	2,576,000	103,040
1884	27,606	1,014,000	1,796	257,000	2,243	35,000	176,755	1,280,000	2,586,000	103,440
1885	18,185	680,000	1,299	187,000	4,533	65,000	187,118	1,311,000	2,243,000	89,720
1886	19,042	762,000	1,292	194,000	3,209	31,000	153,378	955,000	1,942,000	77,680
1887	20,879	897,000	548	92,000	3,490	32,000	185,186	1,183,000	2,204,000	88,160
1888	24,537	1,161,000	414	44,000	3,916	41,000	213,327	1,402,000	2,648,000	105,920
1889	21,184	1,296,000	194	20,000	5,051	43,000	202,431	1,363,000	2,722,000	108,880
1890	15,410	1,200,000	150	16,000	2,980	28,000	186,546	1,259,000	2,503,000	100,120
1891	14,280	1,053,400	70	8,100	1,990	19,100	220,702	1,427,300	2,507,900	100,316
1892	12,260	981,600	60	8,200	2,570	27,400	226,718	1,301,400	2,318,600	92,744
1893	11,310	635,800	67	7,600	6,310	49,000	301,285	1,687,400	2,379,800	95,192
1894	11,600	579,000	160	17,000	3,050	30,000	333,000	1,860,000	2,486,000	99,440

With the exception of small quantities obtained from surface deposits in the provinces of Limbourg and Antwerp, and of the manganiferous ores of the Lienne above referred to, the iron ores are chiefly the produce of Liége, Namur, and Luxembourg.

THE GERMAN EMPIRE.

Germany is undoubtedly the classic land of mining, since it not only comprehends extensive areas of exceptional metalliferous importance, but it was here that the kindred arts of mining and metallurgy were first systematically taught and practised; while at the present time the various mining academies of the German Empire are the resort of students from all parts of the civilised world. The German miner of the middle ages, like his Cornish representative of to-day, was an active pioneer and persevering colonist. In the twelfth century he founded Schemnitz and Kremnitz in Hungary, and three centuries later Schmöllnitz and Kapnik were opened up by miners of the same nationality.

About the middle of the sixteenth century numerous German

[1] The quantities and values of manganiferous iron ores tabulated on p. 354, are included under this head.

miners and smelters were induced to settle in Great Britain, Queen Elizabeth, according to Sir John Pettus, having been advised to take this step "from Her observation of the inartificialness of former Ages in this concern, which may be collected from Her sending for and imploying so many *Germans* and other Foreiners (where *Mines* were plentiful and the *Arts* belonging to them), who might put us into the tract of managing ours, in *finding* and *digging* them, and in *smelting* and *refining Metals*."[1]

Amongst the various States that compose the German Empire, Prussia naturally takes the lead as a producer of metalliferous minerals; for mining purposes it is divided into the five following districts known as *Oberbergamtsbezirke:* Breslau, Halle, Clausthal, Dortmund and Bonn. Next to Prussia comes Saxony as a metal mining country, none of the others being of any importance with the exception of Alsace-Lorraine and Luxembourg, which latter State is usually included as belonging to the German Customs Union. The two last named produce large amounts of brown iron ore, the so-called *minette.*

RHINE PROVINCES, WESTPHALIA, &c.—The ore deposits of this area are exceedingly numerous, and consequently some of the more important only can be noticed.

The oldest account of the occurrence of gold veins in the Eisenberg, near Corbach, is given by Agricola, and it is stated by Brückmann that gold was obtained from this source in the year 1560. Much more recently W. v. Eschwege obtained gold in the form of minute scales from the alluvium of the Edder, but in such small quantities as to render its extraction unprofitable, and moreover he in no case found a fragment of gold adhering to its matrix.

Dieffenbach[2] describes the Eisenberg, near Goldhausen, as being formed of quartzose and clay slates, the former being thinly stratified, much folded, fissured and contorted. Copper ores, particularly malachite, azurite, chrysocolla and cuprite, occur in these fissures; and the siliceous slate in the vicinity of such ores is soft, much decomposed, and impregnated with calcite. The surfaces of the clefts in this rock are also often covered by incrustations of calcite, dolomite, or spathic iron ore, which are sometimes crystallised. In other cases the cavities in the slate are filled with melaconite, which is sometimes moderately abundant. The siliceous slate in the vicinity of the melaconite and other

[1] *Fodinæ Regales*, chap. xxiii.

[2] *Leonhard's Jahrb.* 1854, p. 324.

copper ores, has a cellular texture, and there can be little doubt that this and the other minerals containing copper are the result of the decomposition of pyrites. The gold occurs in the clefts of the quartzose slate, partly incrusting small rhombohedra of spathic iron, which have consequently the appearance of gold crystals, and partly as thin dendritic incrustations upon the surfaces of the clefts. The gold, which is evidently a more recent formation than the crystals referred to, is sometimes covered by small rhombohedra of calcite with rounded edges. The incrustation of gold is at times so extremely thin as to impart a dull brownish colour only to the crystals, and the entire rock, more especially the red clay filling the joints, was found to contain gold. The mode of occurrence of this gold would appear to show that the carbonates of copper and other ores of that metal found in the joints of the slates, are of secondary origin, and that they were derived originally from auriferous pyrites containing copper. Dieffenbach was unable to find any trace of a vein in the siliceous slates, and he was likewise not able to determine whether, at some former period, they were covered by the copper shales which are to be found *in situ* on the flanks of the mountain, and which surround the mines at Goddelsheim.

Alluvial gold, resulting from the disintegration of quartz veins in that district, has been found in the sands of the Goldbach, a tributary of the Moselle, but not in sufficient quantity to repay the cost of extraction.[1]

Numerous veins containing argentiferous galena occur in Devonian rocks in the vicinity of Olpe and Siegen, although but few of them have been more than moderately productive. The most extensive lead mines which have been worked in this district are those of Wildberg and Hideberg, situated upon the same group of east and west lodes. The country rock consists of alternations of schists and slates, with a highly siliceous grauwacke, and the veinstone, which is often to a large extent composed of spathic iron ore, frequently contains, in addition to galena, copper pyrites and blende. The Hideberg Mine is still in operation, but that of Wildberg, which has been worked more or less intermittently from about the fifteenth century, was closed about twenty years ago. There are likewise lead mines in the neighbourhood of Wiehl, Ründeroth, and Siegburg, besides which, considerable quantities of lead ore and blende have been obtained from mines near Bensberg, nine miles east of Cologne.

[1] Nöggerath, *Rheinland-Westphalien*, i. 1822, p. 141.

The group of lodes extending from Holzappel,[1] on the Lahn, to Wellmich and Werlau, on the Rhine, traverse grauwacke and clay slates of Devonian age, and have usually an E.N.E. and W.S.W. direction, with a general dip towards the S.E., but sometimes towards the N.W. "Talcose clay slates" occasionally form a constituent of this formation and are of frequent occurrence in the immediate vicinity of lodes. These rocks, named by the miners *Weisses Gebirge* (white rock), contain numerous beds and veins of quartz, the latter of which often cross the strata nearly at right angles, and are themselves always intersected by lodes.

The Devonian grauwacke rocks enclose deposits of argentiferous lead ores, as well as ores of copper, zinc, and iron. The iron ore forms regular beds between strata of the schistose rocks, superficial deposits of comparatively recent age, or, in the form of spathic iron, is an important constituent of the filling of lodes containing ores of lead, copper, and zinc. The lodes forming the most eastern portion of the group at Holzappel, consist of three distinct leaders, which probably come together in depth, but, like all the other veins belonging to this group, they almost coincide in strike and dip with the bedding of the country rock, and have consequently been sometimes mistaken for metalliferous beds. These lodes have been faulted by two distinct fissures, and have consequently been divided into three portions, of which the most easterly is represented by one only of the three leaders.

The veinstone consists principally of quartz, which sometimes assumes the form of hornstone, with argentiferous galena and blende. Associated with these minerals are tetrahedrite, copper pyrites, spathic iron ore, heavy spar, calcite, and dolomite, which exhibit no regular order of sequence. These ores occur partly as alternating ribbons, but more frequently they are irregularly distributed through the veinstone, which often at the same time encloses fragments of the country rock. Iron pyrites occurs more commonly in clefts in the country rock than in the lodes themselves, which, near the surface, contain numerous products of decomposition, such as cerussite, pyromorphite, cerasine, and anglesite. Blende is represented by smithsonite and goslarite; tetrahedrite by malachite and azurite, and spathic iron ore and iron pyrites by limonite, and by various ochreous iron ores. The ore,

[1] Bauer, *Karsten's Arch.*, 1841, xv. pp. 137–209. Nöggerath, *Rheinland-Westphalien*, iii. p. 216. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd edit., Freiberg, 1859, ii. p. 143.

although not uniformly distributed throughout the lodes, is concentrated in shoots, bunches, or zones, which incline obliquely to the plane of the lodes, at angles varying from 14° to 20°. These are not only nearly parallel to one another, but also to the line which the stratification of the country rock forms with the planes of the lodes. The lodes are usually separated from the enclosing rock by selvages, and sometimes by friction-surfaces, which are generally grooved parallel to the dip of the shoots of ore. There are no geodes in the veinstone, which is, however, traversed by numerous fissures, which do not extend into the country rock beyond. These are often more or less open, and are lined with crystals which are usually of the same mineral as that on which they are deposited. In this way crystals of quartz are generally deposited upon a quartzose matrix, while crystals of galena are found upon masses of the same mineral. With regard to the

FIG. 86.—Holzappel Lode ; Herminen level.

influence exercised by the wall rock upon the contents of the veins, there is, at Holzappel, nothing to show that between certain rocks the veins are always rich, and that, when enclosed in others, they are invariably poor ; a soft crumbling wall rock is, however, more unfavourably regarded by the miners than a moderately hard one. The walls of the lode are by no means perfect planes, but have been twisted and contorted, and in such cases the parts of a lode cutting through the strata are called *Bänke* by the miners.

The walls of the vein fissures show numerous bends and disturbances, while the country rock is frequently arranged in folds, of which the concentric structure is often very remarkable. The fissures intersecting and faulting these lodes are usually filled with clay, which occasionally contains spheroidal masses of ore, similar to those sometimes found in the veins; and through the agency of these fissures the country rock has frequently become impregnated with copper and iron pyrites Fig. 86, after Bauer, represents a section of the Holzappel Lode in the Herminen level, where it varies from fifteen to twenty-five inches in width.

According to A. v. Groddeck the *Weisses Gebirge* of Holzappel, Wellmich, and Werlau, the *Lagerschiefer* of Mitterberg in the Salzburg Alps, and the white slates of Agordo in the Venetian Alps, which previously to his time had been described as "talc slates," or as "rocks resembling talc slate," are *sericite rocks*.[1] He states that analyses of this sericite show that it is a cryptocrystalline potash mica, and that pseudomorphs after felspar, augite, magnetite, and titanic iron ore, are found in the white rock, which must be regarded as an altered eruptive rock, probably diabase. In the white rock of Wellmich are enclosed large crystals of apatite, which he regards as of secondary origin. The variety of white rock called *Lagerschiefer*, and the white slate which encloses needles of clay slate, are probably metamorphic rocks resulting from normal clay slates or grauwacke slates. A knowledge of these rocks becomes valuable as opening up new points of view with regard to various important questions relating to ore deposits, since it would appear probable that the sericite slates always occur in association with ore deposits lying conformably with the strata of the surrounding rock. He further remarks that the deposits of Holzappel, Wellmich, Werlau, and Mitterberg, have, with perfect certainty, been determined to be *Lagergänge* or bedded veins.

The lodes of Holzappel, Wellmich, and Werlau, belong to one *Gangzug* or system of veins, and are accompanied by several parallel systems striking N.E.—S.W., and dipping S.E.; these are:—

1. The Ems Lode-system.
2. " Mahlberg "
3. " Homberg "
4. " Winden "
5. " Weinaur "
6. " Holzappel "
7. " " "

The lodes of the Ems and Mahlberg tracts are *Quergänge* or true veins. The *Lagergänge* only are accompanied by the "white rock," while it is perfectly unknown in the true veins as well as in the lodes in the neighbourhood of Ems. A. v. Groddeck does not offer an explanation for this, but believes that some relation exists

[1] A. von Groddeck, *Jahrb. für Min.*, 1883, ii. "Beilage Band," p. 72.

between the formation of the bedded vein and the metamorphic rocks which the miners call "white rock."

In the year 1881 the Holzappel mines produced 2,119 tonnes of lead ore,[1] and have continued to produce with a fair degree of uniformity; thus their output for 1888 was 1,966 tonnes and in 1894 it was 2,058 tonnes of galena. In addition to the lead ores they have also produced increasing amounts of zinc blende, 6,809 tonnes in 1888 and 9,376 tonnes in 1894. During the last-named year prospecting operations were carried on at the twelfth level with satisfactory results.

The Bunter Sandstone of Bleiberg near Commern, in the Eifel, in the mining district of Düren, contains a deposit of lead ores which has long held one of the most prominent positions among the lead producers of the world.[2] The variegated sandstone of this district may be divided into two portions, an upper, characterised by finely granular red sandstone and the predominance of clays, and a lower, consisting of coarsely granular sandstones of a bright colour and of thick bands of conglomerate. The lower beds of the lower division of the variegated sandstone contain beds of nodular ore, which are principally worked on the Bleiberg between Call and Mechernich.

Above the Devonian beds there is, first, a bed of red clay containing broken fragments of red grauwacke, and above this a mass of conglomerate, from two to twenty feet in thickness, which fills up all the inequalities of the older rock. This conglomerate forms the floor of the *Knottenflötz* or lower seam of nodules, 15 feet in thickness. Above this is a band of conglomerate, which is covered by the upper seam of ore eighty feet in thickness. In some places other bands of conglomerate are interposed in such a way that four seams are separated from one another by beds of varying depths. Many dislocations occur in these rocks, of which the Greisbach main fissure is the most important. The nodular sandstone of the ore seam is white, dirty white, or yellow, and consists of crystalline quartz granules slightly cemented together. The quantity of cement is very small, and the rock is easily reduced to powder. The ore is associated with sandstones of a white colour; when the colour changes, the ore is usually lost.

The lead ore at Bleiberg occurs in the form of so-called *Knotten* or nodules, and the sandstone to which they belong is known as

[1] *Zeitschr. f. Berg. Hütten. u. Salinen. im preuss. Staate.*

[2] C. Diesterweg, *Ibid.*, xiv. 1866, p. 159.

Knottensandstein. Carbonate of copper is present in small quantities. The lead-ore nodules consist principally of galena, and more rarely of cerussite. They are spherical concretions which are scattered through the entire mass of the ore bed. Usually they are smaller than a pea, but in some cases they attain a diameter of one-third of an inch, while on the other hand they sometimes occur as very fine granules only. They consist of quartz grains cemented together with lead ore, with which are associated alumina, lime, and oxide of iron. When galena is present, it is in the form of very finely divided grains deposited between the relatively large particles of sand, and, if examined by the aid of a lens, a crystalline structure is observed. This is of importance as tending to explain the origin of the nodules. When the cementing material is cerussite, it is less distinctly crystallised; in nodules of azurite the cementing copper ore is also in a finely divided state. Nodules of copper ore are most frequent at the Gottessegen Mine. At Berg the copper ore has a considerable extension, but, with its small percentage of copper and the comparatively large amounts of lime and clay present as cement, it is poor and difficult to work. The globular shape of the nodules is best developed when galena is the cementing material; when this consists of white lead or copper ore, the form of the nodules is extremely irregular. The distribution of the nodules in the sandstone is by no means regular; they frequently lie close to one another, and in such cases often grow together, and an irregular ore deposit of considerable extent is the result. In other cases the nodules are from half an inch to several inches apart. At the Bleiberg the nodules in the workable parts of the beds constitute from 4 to 10 per cent. of the weight of the entire mass. Lead and copper ores are rarely found in actual contact, but the nodules often consist of a centre of galena with an exterior coating of white lead; and sometimes the whole of the lead present is in the form of cerussite. The formation of nodules is not necessarily connected with the presence of ore; since similar concretions frequently occur which do not contain a trace of ore, and are known as *taube Knotten.* In addition to the ores of the conglomerate bed and of the *Knottenflötz,* the variegated sandstone of the Bleiberg contains several iron-ore seams which are worked extensively, and which belong to the upper division containing, as its colour indicates, a larger proportion of iron oxide than the lower one. Dr. A. Gurlt is of opinion that the extension of the deposit and the equable distribution of the ores, indicates that they and the sandstone were formed at the same time.[1] The view is now more generally accepted that the lead ore is an impregnation of later date than the formation of the bed itself. Pošepny [2] holds that the mineralising lead solutions found their way into the bed through the numerous fault fissures that intersect it.

Galena and white lead ore occur in Bunter Sandstone in a similar way at Saint Avold, west of Saarbrücken.

The most important mine of the district is known as the Meinerzhagener Bleiberg Mine, and this produces now practically the whole of the ore. The workings are however on a very extensive scale, the sandstone being got both by open-works and by underground mining. The entire district is worked by a Company with a share capital of £320,000, known as the Mechernicher Bergwerks-Actien-Verein, which has just published its thirty-fifth annual report. At one time most flourishing, this Company finds its present position far from satisfactory owing to the low prices of lead and silver, and its annual operations show heavy losses. During the year 1895, there were 2,300 men employed, and 321,881 cubic metres of sandstone in the solid were excavated. The table on opposite page, taken from the above-mentioned report,[3] shows the result of this Company's operations for the last twenty-three years.

The following table shows the amounts of lead ore produced in the entire district through a series of years:—

Year.	1881. Tonnes.	1885. Tonnes.	1890. Tonnes.	1894. Tonnes.
Westphalia	8,663	10,618	10,262	12,901
Hesse and Nassau	21,188	16,091	12,055	11,261
The Rhine provinces	65,951	55,761	60,083	55,249
	95,892	82,470	82,400	79,411

It will be seen that there is a falling off in production, but not a very important one; owing however, to the fall in the prices of lead and silver, the value of the output has greatly diminished as is shown by the annexed table of values in 1881 and 1894:—

Year.	1881. £	1894. £
Westphalia	72,107	64,040
Hesse and Nassau	101,582	53,519
The Rhine provinces	395,305	253,398
	568,994	370,947

[1] *Verhandl. d. naturh. Vereins preuss Rhein. und Westf.*, 1861, p. 60.

[2] F. Pošepny, "The Genesis of Ore Deposits," *Trans. Amer. Inst. M. E.*, 1893, xxiii. p. 313.

[3] *Mechernicher Bergwerks-Actien-Verein, Jahresberichte pro* 1895, April 29, 1896, p. 7.

PRODUCTION OF LEAD AND SILVER FROM THE KNOTTENSANDSTEIN FOR THE YEARS 1873 TO 1895.

Year.	Lead contents of the sandstone per cubic metre of solid rock.		Smelting ore produced from the sandstone.	Potter ore produced.	Lead.	Silver.
	Kilogr.	Per cent.	Tonnes.	Tonnes.	Tonnes.	Kilogr.
1873	43·62	1·71	16,674	1,512	11,883	2,832
1874	48·42	1·90	18,100	1,401	12,672	3,143
1875	40·10	1·57	16,311	1,500	10,599	2,390
1876	39·16	1·59	16,389	1,395	10,911	2,422
1877	42·04	1·65	24,142	1,237	15,762	3,701
1878	38·58	1·51	25,055	1,124	16,041	2,139
1879	46·99	1.84	26,092	1,143	16,692	2,543
1880	45·02	1·77	28,792	972	20,275	5,949
1881	57·59	2·30	33,862	1,078	22,409	4,438
1882	72·55	2·87	38,535	912	25,055	5,108
1883	72·39	2·84	36,524	844	25,582	4,369
1884	71·86	2·92	33,131	965	26,200	5,266
1885	71·36	2·80	33,760	1,079	23,481	5,248
1886	70·22	2·75	30,868	1,107	22,809	6,145
1887	69·94	2·74	33,890	947	23,199	7,803
1888	68·03	2·699	34,576	854	23,845	20,305
1889	59·03	2·315	35,655	819	25,200	9,378
1890	60·24	2·364	36,246	733	24,088	8,195
1891	53·72	2·107	31,895	631	21,550	27,061
1892	57·30	2·247	32,124	647	22,010	33,459
1893	60·75	2·382	34,777	678	20,232	14,666
1894	51·70	2·027	29,099	782	16,002	6,450
1895	47·28	1·854	28,208	732	19,263	17,000

The Eifel limestones, extending from Elberfeld through Balve to Brilon, are traversed by irregular fissures, which occasionally widen out and are filled with calamine, concretionary blende, galena, and iron pyrites, the latter mineral having often become converted into brown iron ore. The largest amount of zinc ore raised in the Brilon district during the year 1881 was produced at the United Bastenberg and Dörnberg Mines, which yielded 6,037 tonnes of zinc ores, and 3,352 tonnes of lead ore.[1] In 1888 the yield was still 3,740 tonnes of zinc, and 5,125 tonnes of lead ore; about this time the mines were seen to be getting gradually poorer in zinc, which was being replaced by lead in the lower levels, and in 1889 these mines only yielded 2,753 tonnes of zinc and 4,089 tonnes of lead ore.

Deposits of a similar character occur in the western prolongation of the Devonian limestone near Altenbühren, Rösenbech, and Bleiwäsche, where the deposits, chiefly composed of smithsonite with a little galena, are only of commercial importance when enclosed in Devonian limestone.

[1] *Zeitschr. f. Berg. Hütt. Salinenw.*

Very similar deposits are found in the magnesian limestone of the same age at Gladbach, ten miles east of Cologne, where an irregular bed of lignite is found almost immediately above the magnesian limestone, the surface of which is extremely irregular, containing hollows in which occur the ores of zinc. These consist of calamine, with a little galena, enclosed in clay; and similar deposits of detached fragments of zinc and lead ores are not of unfrequent occurrence in the clay of the lignite formation at a considerable height above the hornstone. Von Huene observes with regard to this deposit that, up to the date of his writing (1852), no particles of blende which had withstood alteration have ever been found in it.[1] At the Frühling Mine, near Altenbrück, two miles east of Bensberg, on the contrary, the blende has only been completely changed into calamine at the outcrops of the deposits, while at greater depths unaltered blende is found enclosed in the larger masses of calamine. The mode of occurrence of the zinc ores at Gladbach and at various other localities in the same neighbourhood, would appear to indicate that they are no longer in their original position, but that they were carried into the basin-like depressions which they now occupy by the mechanical action of the water by which the clays of the lignite formation were deposited. The outlines of these fragments are usually rough and sharply defined, and it therefore appears improbable that they have been transported from any considerable distance. It is consequently quite possible that they may have been derived from the outcrops of lodes containing blende and galena of a similar character to those now worked in the neighbourhoods of Bensberg and Altenbrück.

It is to be remarked that the calamine deposits on the left bank of the Rhine are associated, principally, with Carboniferous limestones, while those on the right bank of that river for the most part occur in rocks of Devonian age.

The largest quantity of zinc ore produced in the Düren district in 1881 was obtained from the Altenberg Mine,[2] belonging to the Vieille-Montagne Company, which yielded 17,464 tonnes of zinc ores. against 13,135 tonnes during the previous year. This is the most productive of several mines owned by the above Company in this neighbourhood, and its output forms the bulk of that of the district.

In the Düren district four mines were working during the year 1881, and together produced 17,121 tonnes of blende and 8,560

[1] *Zeitsch. d. deutsch. geolog. Gesellsch.*, 1852, p. 575.

[2] *Zeitschr. f. Berg. Hütt. u. Salinenw.*, xxx. 1882, p. 175.

tonnes of calamine, of the total value of £22,548. The total output of the district in 1894 was 14,035 tonnes of blende, and 6,275 tonnes of calamine, worth together £39,640.

The Rhine provinces produced in 1894 over ten times as much blende as they did calamine, the proportion of the former to the latter increasing gradually as the mines are worked at deeper levels.

The copper deposit of the Friedrich-Wilhelm Mine at Berg, near Commern, is, like the lead ores of the immediate neighbourhood, situated in Bunter Sandstone. The bed containing the copper ore strikes from north-west to south-east, dips towards the north-east, and has an average thickness of about nine feet. This bed, like the lead ore deposits at Bleiberg, contains the ore for the most part in the form of small nodules. Galena occurs subordinately, and copper and iron pyrites are found in pockets associated with heavy spar. The copper ore nodules consist principally of malachite and azurite, copper glance, chrysocolla, and cuprite. The sand in which the nodules are enclosed consists of quartz fragments united by a cement containing carbonate of lime. This sandstone is more or less ferruginous, and chrysocolla, brown iron ore, oxide of manganese, and calcite occur in its fissures.[1]

The amount of copper which has been furnished by this mine is apparently small. In the year 1853 it yielded 25 tonnes of ore containing from 6½ to 9 per cent. of copper, and 1,508 tonnes in which the percentage of that metal varied from 1½ to 2½. Its most productive year was 1856, when the output was 3,179 tonnes containing from 0·75 to 3 per cent. of copper. During the two following year the workings were suspended, but in 1859 the yield amounted to 192 tonnes of ore containing from 1 to 2 per cent. of copper; in 1860 the yield was 139 tonnes of 1½ per cent. ore, and in 1861 the mine was abandoned on account of the large percentage of lime present in the ores.

The Devonian strata in the neighbourhood of Dillenburg,[2] which are traversed by dykes of diabase as well as penetrated by pyritous serpentine, consist partly of *Schalstein*,[3] and enclose numerous copper lodes. These veins vary in their strike from north and south to east-south-east and west-north-west, and have usually a considerable dip. The veinstone is principally quartz, clay, brown spar,

[1] W. Jung. *Berg. u. Hüttenm. Zeitung*, 1862, p. 229.

[2] Stifft. *Geogn. Beschr. d. Herzogth. Nassau*, 1831, p. 486.

[3] *Schalstein* is a consolidated ash bed, probably resulting from the eruptions to which the diabase owes its origin.

heavy spar, and calcite. The ore is chiefly copper pyrites, but copper glance, cuprite, malachite, azurite, and chrysocolla are sometimes also present.

The influence exercised by the country rock upon the contents of the veins is very apparent. In diabase the ores are rich in copper but are not very abundant, quartz is the prevailing veinstone, and clay selvages are entirely wanting. On the other hand, in *Schalstein* the lodes have distinct selvages, the veinstone is mainly composed of calc spar, brown spar, and heavy spar, and the ores, although perhaps more abundant, are not usually so rich. The rock in which the veins are on the whole most productive is a decomposed *Schalstein* much stained by hydrated ferric oxide, and which, in the immediate vicinity of the lodes, is often more or less impregnated with copper ores. In the sandstones and Cypridina slate the lodes usually contain but little ore, and the quartz, which under such circumstances is the prevailing veinstone, often merges gradually into the country rock, so that the veins are without sharply defined walls.

Sandberger[1] has determined the presence of copper in the augite in both the diabases and basalts of this district, which may probably explain the origin of the copper contained in the veins. Both galena and blende are sometimes associated with copper pyrites in calc spar, filling fissures in the Nassau diabase, as well as in the copper veins themselves, but they usually occur in very small quantities only, either alone or associated with arsenical fahlerz. Where in depth the diabase becomes compact, the veins are usually without ore, and are represented by fissures principally filled with clay. Senfter has found lead, zinc and arsenic in the diabases of this region, and it is consequently not improbable that under favourable circumstances these metals may become concentrated in the form of ores.

A group of veins extending from Rossbach to Roth yields tetrahedrite containing silver and sometimes a little mercury, while cinnabar occurs in the copper lode at the Neuermuth Mine at Nanzenbach, and traces of the same mineral are found in the hæmatite which generally occurs in the *Schalstein* of the district.

A considerable number of veins very closely resembling one another in other respects, but differing considerably in their strike, have been opened up by the workings at the Hülfe-Gottes Mine at Nanzenbach. Some of these lodes have contained a sufficient

[1] F. Sandberger, *Berg. und Hüttenm. Zeitung.*, 1877, p. 390.

amount of nickel to admit of its being extracted with advantage.[1] The nickeliferous ores contain on an average from 12 to 15 per cent. of copper and about 3 per cent. of nickel. Arsenic and cobalt are not usually present, but sometimes occur at the intersection of the lodes by cross-veins.

Ores of antimony sometimes occur in the Devonian rocks of Rhenish Prussia between Wintrop and Uentrop, four miles from Arnsberg, where a bituminous limestone, from six to eighteen inches in thickness, alternates with clay slates and siliceous shales. All of these strata, which are overlain by Millstone Grit, are occasionally penetrated by stibnite, which is usually most plentiful towards the middle of the various beds, and gradually becomes less so near their planes of separation.[2] The more massive portions of the stibnite sometimes include fragments of the enclosing rock, and the ore not unfrequently penetrates into cracks and fissures. Cervantite, antimony ochre, is found as a product of alteration near the surface, and the rock sometimes contains a little iron pyrites, blende, calcite, and fluor spar. As early as the year 1833 the Caspari Mine had opened up eleven of these metalliferous strata, near which, but without any apparent connection with them, are veins of heavy spar containing copper pyrites and ores of bismuth. At the Hoffnung antimony mine, near Brück on the Ahr, the Devonian slates strike nearly north and south with a dip of about 45° towards the west. The ores of antimony occur over a band which is sometimes as much as 120 feet in width, and which in 1827 had been opened upon, in the direction of the strike of the strata, for a distance of about 560 feet. The stibnite, which is associated with iron pyrites and brown spar, is found partly in true veins and partly between the planes of stratification, or in cleavage fissures.

Iron ores occur in the Devonian rocks of the Duchy of Nassau in the form of beds, lodes, bedded and contact deposits, and surface deposits.[3] In the neighbourhood of Dillenburg and Wetzlar, numerous beds of hæmatite occur associated with *Schalstein*, and, according to Sandberger, these deposits, which are frequently very irregular, invariably occur in connection with either diabase or *Schalstein*, being sometimes bounded by either

[1] v. Koenen, *Zeitschr. d. d. geol. Gesellsch.*, 1863, xv. p. 14.

[2] Buff, *Karsten's Arch.* vi. 1827, p. 54, and 1833, vi. p. 439. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, ii. p. 154.

[3] F. Sandberger, *Uebers. der geol. Verh. v. Nassau*, 1847, p. 27. H. Bauerman, *Metallurgy of Iron*, London, 1882, p. 80. A. Nöggerath, *Zeitschr. f. Berg. Hütt. u. Salinenw.* xi. 1863, pp. 63–94.

of these rocks on one side and on the other by Cypridina slates. They contain numerous fossils, and are worked in five to six hundred small mines in the Duchy of Nassau alone. Stifft says of these deposits that they are distinguished as *Fluss-lager* when containing calc spar, and as *kieselige Lager* when quartz is present in notable proportion. The first often lie entirely in *Schalstein;* while diabase in many cases forms the hanging wall but never the foot wall. The siliceous beds are found entirely in diabase. In addition to hæmatite, limonite also occurs in this district, but generally in association with limestone.

A short distance north of Stockhausen, on the Lahn, a bed of iron ore occurs in *Schalstein*, near its point of contact with labradorite-porphyry; and south of Brilon, in Westphalia, a chain of porphyritic domes occurs in the Upper Devonian series, which are accompanied by lenticular deposits of hæmatite at their junction with the stratified rocks. Lodes of spathic iron ore, partially altered into limonite, frequently occur in this part of Germany, and often contain a greater or less amount of copper or lead ores, thus gradually passing into lodes of these metals with a veinstone composed of more or less altered siderite.

Large quantities of spathic iron ores occur in the Devonian rocks of the Siegen district, the most important deposit being that of Stahlberg near Müsen, where a nearly vertical wedge-shaped vein, enclosed in clay slate, has been worked since the year 1313. The greatest thickness of this mass is about seventy-five feet, its horizontal extension about 160 yards, and its depth, which has been proved by twelve working levels driven into the hill side, 260 yards. The entire mountain belongs to the so-called Coblenz beds of the Lower Devonian formation which predominates throughout the Siegen district. Clay slate is the prevailing rock, the most usual variety being grayish with an imperfect cleavage, but lustrous bluish-gray slates with a typical slaty structure are also met with, as are likewise brownish-red slates called *Fuchs* by the miners. The last two varieties exercise an impoverishing influence upon the lode, and beds of hard grauwacke are frequently interstratified with the slates. The strike of the strata is north-east and south-west, with a dip of about 45° towards the south-east. The vein traverses the bedding with a dip of from 80° to 85° towards the south-east and maintains its maximum width for a distance of 60 yards. Well-defined selvages are but rarely met with, and the country rock, which is principally clay slate, is almost always traversed for several yards from the lode by numerous strings of spathic iron ore. On the north, hard bands of grauwacke occur with beds resembling roofing slate; and, when these constitute the country rock, they cause the almost entire disappearance of iron ore. The lode splits into three leaders, varying from six to thirty-six feet in width, which, together with the interpolated wedge-shaped masses of country rock, attain a united thickness of 180 feet, proceed for a distance of 120 yards in the direction of the strike, and then continue as insignificant strings of quartz. The lode consists almost exclusively of spathic iron ore of a yellowish-white colour, containing about 11 per cent. of manganous oxide, and which rarely changes into brown iron ore. In drusy cavities in this lode rhombohedral crystals of spathic iron ore, one and a half inches in diameter, are sometimes met with. These crystals have curved faces, and are always accompanied by crystals of quartz. Other ores, such as iron pyrites, copper pyrites, fahlerz, and galena, are met with at several points in the lode, and are comparatively abundant in the adjoining mine of Schwabengrube. The production of Stahlberg in one year never exceeded 36,210 tonnes, and in 1881 the yield amounted to only 2,657 tonnes of iron ore.[1] In 1894 the Müsen district only produced 2,184 tonnes of iron ore. The Siegen district was however a large producer with an output of 760,000 tonnes; the most important mines, those of Storch and Schöneberg, produced 237,900 tonnes of spathic ore.

The Carboniferous formation of the Ruhr district in Westphalia,[2] as at Essen, Bochum, Hörde, and various other localities, contains parallel deposits of ironstone closely resembling the blackband of the Scottish coal-fields. In addition to beds of compact ironstone, a nodular concretionary variety is of frequent occurrence in the shales of this formation. The ironstone deposits of the Carboniferous formation in the neighbourhood of Saarbrücken are usually more productive than those of the Ruhr, and for the most part consist of lenticular concretions of sphœrosiderite; this mineral also occurs in the lignite near Bonn.

Some valuable bedded manganese deposits have been opened recently in the Bonn district; their output was not important before 1885, in which year, however, they were largely developed, and from that date onward formed the chief source of manganese for the whole of Prussia; thus in 1887 out of a total of 36,534

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.*, xi. 1863, p. 93. *Ibid.* xxx. 1882, p. 164. *Ibid.* xliii. 1895, p. 133.

[2] B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd edit. ii. p. 120.

tonnes of manganese ore valued at £47,590, the Bonn district produced 36,516 tonnes. The chief mines are in the neighbourhood of Weilburg; of these Gilsahaag produced 12,967 tonnes, and Altengrimberg 10,491 tonnes in the same year. The district produced 43,982 tonnes in 1889, but the output fell slightly, to 33,096 tonnes, in 1893.

Another mineral product that has risen to great importance is iron pyrites, the chief deposits of which are near Meggen on the river Lenne.[1] This district, which has produced over three-fourths of the pyrites of Germany, was first opened up in 1853 for pyrites mining, although the oxidised ore of the outcrop had long been mined as brown hæmatite for use as an iron ore. When the deposits were found to change into pyrites in depth, they were abandoned and were only re-opened when a demand sprang up for pyrites, as a source of sulphur. The ore seems to occur in the form of bedded veins some 10 feet in thickness, accompanied by barytes and intercalated between Upper Devonian shales. The maximum output was reached in 1872 with 143,476 tonnes; from this figure it fell in 1878 to 59,920 tonnes, rose again in 1882 to 111,159 tonnes, and in 1886 was 81,285 tonnes. In the latter year the output of pyrites in Prussia was 104,374 tonnes and in Germany 113,655 tonnes. Most of the mines are controlled by two companies, Silicia and Siegena, which amalgamated some years ago; their joint production in 1894 was 115,781 tonnes, that of the whole of Prussia being 123,149 tonnes, valued at £43,119.

The Black Forest.[2]—The Black Forest, which rises to an average height of about 3,000 feet above the sea level, consists chiefly of granite and gneiss, which occasionally alternate with and pass into one another. These are sometimes traversed by various eruptive rocks, such as porphyries, diabases, and serpentines. A small area of clay slate, probably of Silurian age, appears to merge gradually into the gneiss near Todtenau, and there are some remains of Carboniferous strata near Schramberg and Offenburg, in which are found seams of anthracite. The New Red Sandstone is extensively developed in the neighbourhood of Baden-Baden, where it reposes immediately upon crystalline rocks. In the southern portion of the region Bunter Sandstone sometimes occurs on the granitic heights of the Black Forest, and often covers them

[1] M. Braubach, *Zeitsch f. Berg. Hütt. u. Salinenwesen*, 1888, xxxvi. p. 225.

[2] Braun, *Ann. des Mines*, xvii. 1843, p. 115. Selb. *Leonhard's Taschenbuch*, 1815, p. 320. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd ed. ii. p. 171. F. Sandberger, *Untersuchungen über Erzgänge*, 1882, Part 1, p. 40.

in the form of isolated caps. On the western declivity of the mountains, which descend rapidly towards the valley of the Rhine, is a succession of sedimentary rocks tilted into a nearly vertical position.

Veins containing ores of silver, lead, copper, nickel, cobalt and antimony, associated with heavy spar, fluor spar, calcite and quartz, are not of unfrequent occurrence; the majority of them are, however, too poor to admit of their being advantageously worked, and only at long intervals contain rich pockets of mineral. The lodes in this region are said to owe their origin to eruptive rocks, and especially to porphyries, which they always intersect whenever they come in contact with them. The galena found in these lodes is said to become gradually poorer in silver in proportion as the rocks traversed by the lodes are of more recent age. Important deposits of pea iron ore are found in various localities, and particularly in the neighbourhood of Kandern; there are also veins of limonite, which sometimes contain ores of manganese. Gold is found in the alluvium of the Rhine; and deposits of calamine occur at Wiesloch, in Baden.

The Kinzig Valley is chiefly composed of granite and gneiss, which, on the tops of the highest hills, are sometimes overlain by Bunter Sandstone. In this valley the crystalline rocks are frequently traversed by veins containing ores of silver, lead, copper, nickel and cobalt, associated with heavy spar, calcite, brown spar and quartz. These minerals occur so intermixed with one another that the lodes cannot be classified into distinct groups in accordance with the metals which they yield, and in some cases all the various ores above enumerated are found in the same vein. Notwithstanding the large number of veins in this district it has never been a continuously prosperous mining region, as the rich ores only occur in patches of limited extent at great distances apart.

The Wenzel Mine, in the Wolfach district, is said to have yielded large profits during the early part of the last century, and the Alter St. Joseph Mine, near Wittich, was, at about the same period, worked for native silver, argentite, and smaltite. The rare mineral, wittichenite, cupriferous sulphide of bismuth, also occurred in this mine. The Sophie Mine, in the same neighbourhood, was also at one period very celebrated, producing native silver, argentite, pyargyrite, native bismuth, bismuthite, realgar, and copper nickel. Other similar lodes are known in the district, some of which have yielded ores of copper. Braun states that these lodes penetrate the Bunter Sandstone, and mentions one at the Güte-Gottes Mine which has granite as its foot wall and sandstone as its hanging wall. Among the other veins of the Kinzig Valley is the Friedrich-Christian, near Schapbach, (p. 102), which produces galena, schapbachite or bismuth silver, and copper pyrites. Native silver, native copper, cuprite, and chalcocite occur at the Leopold Mine in a matrix of quartz and heavy spar. Similar lodes, although containing less ore, occur in various formations overlying the granite and gneiss, namely, in clay slates, Carboniferous sandstones, Bunter sandstones, and *Muschelkalk,* and they even extend into rocks of Jurassic age, in which heavy spar is the only veinstone.

In the southern portion of the Black Forest granite and gneiss again predominate, but they are here associated with rocks of Silurian age, which gradually pass into gneiss, while remains of the Bunter Sandstone are sometimes found upon the higher ground. The veins in the neighbourhood of Sulzburg, like those in the Kinzig Valley, yield ores of many different metals, but the most remarkable mine of this region is probably the Haus Baden and Carl, near Badenweiler. The lode in this place is sometimes as much as twelve feet in width, and may be regarded as a contact deposit between granite and Bunter Sandstone, but it is separated from the granite by a mass of porphyry some forty-five feet in thickness, which itself contains galena, heavy spar and fluor spar. The veinstone is composed of heavy spar, fluor spar, and quartz, containing argentiferous galena, copper pyrites, and chalcocite, which near the surface have frequently become transformed into various secondary minerals.

The lodes of the Münster Valley closely resemble those in the neighbourhood of Sulzburg, while similar veins occur in the Hofsgrund, on the Erzkasten, and in the neighbourhood of Todtenau.

In the middle ages gold washing was actively carried on in the Rhine Valley between Mannheim and Basle, and v. Cotta states that, in 1859, 400 persons were occasionally employed in gold washing in the Grand Duchy of Baden. The gold is found among the sands and pebbles on the banks of the Rhine, associated chiefly with ilmenite and rose-coloured quartz, in scales never exceding a millimetre in diameter. The entire bed of the river is auriferous, but it is in certain localities only that the sands will repay the expenses of working. The gold-washings commence below Basle, in the neighbourhood of Istein and Alt-Breisach, but the most productive localities are between Kehl and

Dachslanden, especially opposite the village of Helmlingen; there are also a few washings below Philippsburg, but their yield is exceedingly small, so that they have been abandoned for a considerable time.

Calamine occurs in the *Muschelkalk*, but this deposit differs materially from those of Upper Silesia, which occur in the same formation. According to official documents, mines of argentiferous galena were worked in the range of hills between Nussloch and Wiesloch as early as the eleventh century, but mining for calamine was not commenced until the year 1851. The rock is intersected by vertical fissures, in which carbonate of zinc without any admixture of silicate occurs, accompanied by brown iron ore and galena. When the encrinital beds rest upon the compact limestone the fissures often widen out and contain very rich ore. The presence of numerous fossils converted into calamine indicates that the formation of the ore is the result of the alteration of limestone into calamine.

Extensive deposits of pisolitic iron ore are found in the Jurassic formation in the vicinity of Kandern, Stockach, Möhringen, and Jestetten, as well as more to the north in the Baier Valley. The longest worked and most important of these mining districts is that of Kandern, where the iron ore forms part of a sandy deposit varying from one to one hundred feet in thickness, and which, for the most part, overlies rocks of Jurassic age. This deposit, which is known as the *Erzgebirge*, in some places comes to the surface, or is covered by alluvial detritus, but is more frequently overlain by a Tertiary limestone conglomerate locally known as *Steingang*. In 1865 about eight mines were working in the district around Kandern and Kleingau, and iron mines are said to have been in operation in this part of Germany for more than ten centuries.

Immediately below the vegetable soil at Mösskirch is a layer of some inches of sand, beneath which are several inches of pisolitic iron ore mixed with pebbles, sand, and sharks' teeth. Below this is another layer of sand, covering the chief deposit of iron ore, 3½ feet in thickness, containing boulders associated with shells, sharks' teeth, and Oolitic and Tertiary fossils. The whole is firmly cemented together by hydrated ferric oxide, while the boulders, which are principally quartz, frequently contain white mica. Flinty concretions are sometimes met with, and angular or rounded fragments of Tertiary sandstones are by no means of unfrequent occurrence.

The miners distinguish two kinds of ore; namely, *Reinerz*, pure ore, and *Bohnerz*, pisolitic ore. The first of these is a lamellar, compact, or fibrous ironstone occurring either in patches, or in nodular concretions which sometimes, although rarely, attain a diameter of two feet. They are covered by a yellowish or brownish-red incrustation, and when broken are found to be composed of concentric layers, or to be fibrous, compact, or even porous. Their interior is generally hollow, or is occupied by a kernel of clay or sand. When hollow the surfaces of the cavities are often lined by incrustations of hæmatite, by fibrous limonite, or by crystals of brown spar, spathic iron ore, or calcite; even Jurassic fossils are occasionally found enclosed in the nodules of clay ironstone. The *Bohnerz*, like the *Reinerz*, forms continuous nests or beds, but the two sometimes occur together in the same deposit. The larger nodules of *Bohnerz* vary in size from a pea to a walnut, and are always formed of concentric layers more or less firmly cemented together. Jasper likewise occurs with both varietes of ore, and is always gray when associated with *Reinerz*, but may be either gray or red when found with *Bohnerz*.

B. v. Cotta says, with regard to these deposits, that the separate members of the two varieties of ore, including the jasper, evidently belong to the Jurassic period, but were deposited in their present position during Tertiary times, as is shown by the sharks' teeth, bones, and fragments of Molasse sandstone which accompany them. He further remarks that the nodules of ore and jasper cannot be ordinary pebbles as, if so, their external form would not so exactly correspond with their internal structure.

THE PALATINATE.—Ores of mercury occur in the eastern portion of the Saarbrücken Coal-basin in lodes, as impregnations in slates, sandstones, and ironstones, and as conglomerates of Lower Permian age, as well as in the melaphyres, amygdaloids, and porphyries which have in various places burst through them. Lodes containing ores of this metal are found at the Potzberg in sandstone and argillaceous shale; at Mörsfeld in melaphyre-conglomerate, claystone-conglomerate, and claystone; at Rathsweiler, Erzweiler and Baumholder in melaphyre and amygdaloid; and in the Königsberg and Lemberg in quartz-porphyry. These veins are sometimes accompanied by claystones and hornstones, which are otherwise unknown in the district, and may perhaps be products of the alteration of sandstones and ordinary clay slates. In claystones and hornstones the lodes are usually metalliferous, but become comparatively unproductive upon passing into other rocks. Sandstones and conglomerates have sometimes contained rich deposits of ore, but the clay slates are almost invariably barren. The only known exception to this rule is the occurrence of cinnabar in the casts of fossil fish, in the clay slate near Münsterappel, on the right bank of the Appelbach.

The lodes of this district are for the most part associated in small groups in which the principal leaders assume a certain parallelism, but both lodes and impregnations appear to be productive at short distances from the surface, only to become gradually poorer as greater depths are attained. The greatest depth reached at Potzberg, Landsberg, and Mörsfeld, was about 120 fathoms. Cinnabar is the most common ore of mercury present, and usually occurs in the form of thread-like strings, or as crystals in small drusy cavities either in the vein or in the country rock. The other mercurial substances present are native mercury, native amalgam, calomel, and, more rarely, mercurial fahlerz. Generally speaking, the lodes are principally filled with clay, but calcite, heavy spar, quartz, hornstone, chalcedony and bitumen are also sometimes present. The associated minerals are iron pyrites, which is sometimes argentiferous, red and brown hæmatite, spathic iron ore, galena, fahlerz, copper pyrites, pyrolusite, and psilomelane. The extension in the direction of its strike is, at Landsberg, on the Gotte gabe Lode, 450 fathoms. The Mörsfeld lodes extend for a length of about 200 fathoms, but very few of the others are more than 100 fathoms in length.

Important mines of quicksilver sprang up at Obermoschel and Landsberg,[1] in the Palatinate about the middle of the fifteenth century, and the Erzengel Mine alone is said to have afforded as much as 9,000 lbs. of quicksilver annually. In the year 1765, the Palatinate Zweibrücken mines together yielded 43,000 lbs. of quicksilver, but they have now for many years become almost completely exhausted. In the year 1879,[2] the mines of Lemberg and Kellerberg were re-opened, but their production has been very small; in 1879 they yielded 14·25 tonnes of ore, worth about £20; and in 1880, 29 tonnes of the value of £35. No returns of ore seem to have been made since that time.

THE HARZ.—Mining in the Harz was first begun in the year 933,[3] or according to some authorities in 968, during the reign of

[1] H. v. Dechen, *Karsten's Archiv.* xxii. 1848, pp. 375–464.

[2] *Zeitschr. f. Berg. Hütt. u Salinenw*, xxviii. 1880, p. 186. *Ibid.*, xxix. 1881, p. 189. *Ibid.*, xxx. 1882, p. 187.

[3] Conrad Blömeke, "Über die Erzlagerstätten des Harzes," *Berg. u. Hüttenmännisches Jahrbuch*, 1885, xxxiii. p. 1.

Otto I., the first workings having been commenced at Rammelsberg, near Goslar. Between the years 1004 and 1006 the mine was abandoned in consequence of plague and famine, but was resumed in 1016. In the fourteenth century the workings at Rammelsberg fell in, 400 miners were killed, and in consequence mining was abandoned for about 100 years. In 1473 the Meissner Adit was begun by miners from the Meissner district, who understood working in hard rock with the gad and hammer better than the local miners, and blasting with powder was tried in the middle of the fifteenth century. In 1820 the Rammelsberg was removed from the jurisdiction of the town of Goslar and handed over to the *Communion Harz Verwaltung*, which is so divided, in accordance with a convention dating from 1635, that Hanover, now the kingdom of Prussia, receives four-sevenths and the Duchy of Brunswick three-sevenths of the profits.

Mining was begun at Zellerfeld, Wildemann, and Clausthal, in the upper Harz, in the year 1000. Mining flourished in the thirteenth century, but came to a standstill in the middle of the fourteenth, on account of difficulties experienced in draining the mines. At the beginning of the sixteenth century the mines were worked on an extensive scale, but were again abandoned during the Thirty Years' War. Owing to improvements which had in the meantime been made in pumping machinery, the mines were successfully re-opened at the beginning of the eighteenth century and have continued in operation to the present day.[1]

The Harz comprehends an approximately elliptical, upland area, the greater axis of which is twice as long as the smaller, consisting for the most part of sedimentary formations of Devonian and Lower Carboniferous age.[2] Grauwacke, clay slate, siliceous slate and quartzite are the predominating rocks, with subordinate beds of limestone. These strata are frequently broken through by igneous rocks, especially by the granite masses of the Brocken and Ramberg. It is noteworthy that the granite of the Harz contains remarkably few mineral veins, and of these none carry any precious metals though some bear ores of iron and manganese. The most important is the manganese vein of Braunlange, which is remarkable as being the only vein in this district that has hitherto been found to continue from the granite into the slate, or *vice versa*.[3]

[1] Dr. A. Gurlt, *Bergbau und Hüttenkunde*, Essen, 1879, p. 16.

[2] A. v. Groddeck, *Abriss der Geognosie des Harzes*, Clausthal, 1833, p. 22.

[3] Conrad Blömeke, "Über die Erzlagerstätten des Harzes," *Berg. u. Hüttenmännisches Jahrbuch*, 1885, xxxiii. p. 1.

Around the older rocks is a mantle of more recent formations, namely, Upper Coal-measures, Permian, Triassic, Jurassic and Cretaceous rocks, which may be regarded as defining the limit of the mountain district.

The principal riches of the Harz consist in lodes and deposits of silver, lead and copper ores, sometimes united with ores of cobalt and nickel; in lodes of antimony; in deposits of pyrites; and in lodes, beds, and deposits of ores of iron and manganese. The copper schist of Mansfeld, in the Lower Harz, is very extensively worked.

The lodes producing ores of these metals occur chiefly in the Devonian and Lower Carboniferous rocks of Clausthal and Zellerfeld, in the Devonian rocks of the Rammelsberg, in the Silurian rocks of St. Andreasberg, and in slate of the same age at Harzgerode in the Eastern Harz.

A. v. Groddeck describes [1] the celebrated lodes of the North-west Upper Harz, on the plateau of Clausthal, as traversing Devonian strata and Culm-measures, and states that a displacement of the country rock to a distance of 218 yards occurs at Bockswiese and Lautenthal, where the lode fissures have Devonian strata on the foot wall and Culm-measures on the hanging wall. The lode-groups form a system of rays which spreads out from the Upper Kellwasserthal, beneath the Brocken, towards the west. In this system three main rays may be distinguished: the most southerly of which has a general strike of N. 75° W. (7 o'clock[2]), and is formed by the Silbernaaler group, the United Burgstädter and Rosenhöfer groups, and the Schulerthaler group. The Lautenthal-Hahnenkleer and the Bockswiese-Festenburg-Schulenberger groups, which have a general strike N. 45° W., belong to the middle ray. The eastern ray is composed of a group which, up to the present time, has not been much investigated: its direction is N. and S. Between these main lodes, especially between the south and middle groups, several others occur, among which may be mentioned the Zellerfelder, the Herzberger, and the Hütschenthal-Spiegelthaler groups. Next to the metalliferous veins are two destitute of ore, the *faule Ruschel* and Charlotte Lode, which run nearly parallel to the strike of the beds, namely, from N. 45° to 75° E.

[1] A. v. Groddeck, *Zeitschr. d. d. geol. Gesellsch.* xviii. 1866, p. 693, and xxix. 1877, p. 440. *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxi. 1873, p. 1. B. Rösing, *Ibid.* xxv. 1877, p. 280.

[2] In expressing the strike in hours we must imagine the horizon to be divided into twice 12 hours, each hour representing 15°. The direction N.S. is hour 12, midnight and midday; E.W. is hour 6, morning and evening.

The lodes, which have distinct selvages on the foot wall, are split up and mixed with the country rock on the hanging wall, and sometimes reach a thickness of more than 20 fathoms; their dip is at a great angle towards the south and south-west, rarely towards the north or east. The filling of the lodes principally consists of country rock, grauwacke, and clay slate in a more or less altered state, together with lustrous black slate. Between these fragments of country rock, the gangue and ores lie in the form of strings and impregnations; brecciated lodes are very general. The gangue is quartz, spathic iron ore, calc spar and heavy spar; the principal ores being argentiferous galena, blende and copper pyrites. These ores are very unevenly distributed in the lode cavities, and numerous veins are characterised by the predominance of a quartzose gangue, with galena, as in the case of the Zellerfeld lodes; others, such as the Burgstädter lodes, are filled with quartz, calcite, galena, and blende. In some places copper pyrites occurs, as at the Charlotte Mine, or zinc blende, as at Lautenthal, where it is the principal ore. In an exhaustive memoir, F. Schell[1] has described the lodes of the North-western Upper Harz as having a general strike from south-east to north-west. Formerly they were represented as being parallel, and this to a certain extent is true, although it can no longer be considered as strictly correct. The whole system of lodes should rather be regarded as a network, because they are almost all connected either by intersecting veins or by flucans. The majority of the lodes dip to the south-west, and on this account have been termed "right dipping" in contradistinction to those inclined in the opposite direction, which are styled "reverse dipping." The latter occur chiefly in the Rosenhöfer lode-group. In describing the lodes according to their character and constitution, it is desirable to employ the expression *Gangzug*, lode-group, because it signifies to a certain extent that they were formed at one time, or may even be at present in course of formation.

Commencing in the south and ending in the north, these lode-systems are the following:—

1. The Laubhütter-Adit lode-group.
2. The Hülfe-Gotteser and Isaakstanner lode-group.
3. The Silbernaaler lode-group.
4. The Rosenhöfer lode-group.

[1] "Der Bergbau am nordwestlichen Oberharze," *Zeitschr. Berg. Hütt. u. Salinenw.* xxx. 1882, p. 83.

5. The Burgstädter lode-group, and the Zellerfelder main lode-group.
6. The Haus-Herzberger, Spiegelthaler and Spätenthaler lode-group.
7. The Schulenberger and Bockswieser lode-group.
8. The Hahnenkleer and Lautenthaler lode-group.

The Rosenhöfer group has the most complicated network of lodes of any in the North-western Upper Harz. Forming part of it is a perfect entanglement of veins, completely shut in by two main lodes, namely, by the hanging wall of the Thurmhöfer and foot wall of the Liegender-Altensegener Lode. Between these the most varied fissures occur, containing more or less ore. There are

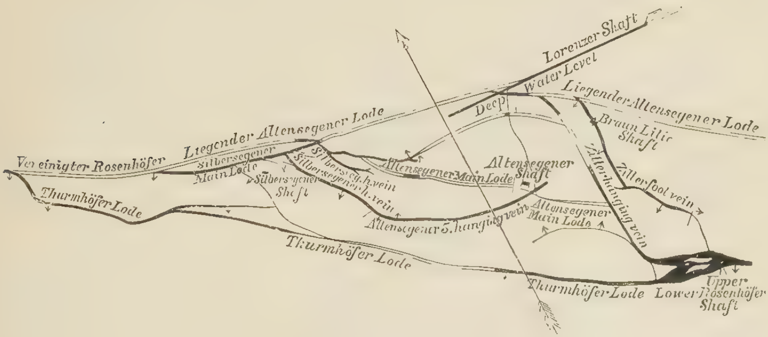


Fig. 87.—Rosenhöfer lode-group; horizontal section.

also several diagonal lodes which render the mapping of this network still more difficult, namely, the Ziller foot vein and hanging vein and the Braunlilier Vein. Within the network are several reverse-dipping veins, and lastly there is the *faule Ruschel* coming from the Burgstädter Hauptzug which joins the Altensegener Lode.

Fig. 87, which is a horizontal section of the group along the water-level, will not only serve to give an idea of the position of the various branches, but also furnishes an example of the general mode of occurrence of mineral veins in the Upper Harz. From the drawing it will be seen that near the south-eastern shafts of the Rosenhöfer group, as well as somewhat further east and west, the lode fissure has widened considerably through the union of several veins. The Thurmhöfer Lode emanates from its hanging wall, while the foot wall of the Altensegener Lode is connected by two diagonal cross-courses with the main fissure.

The contents of the Rosenhöfer Lode consist of spathose iron ore, in addition to argentiferous galena, and on this account its ores are easily fusible. Beautiful specimens of fahlerz are met with in the Silbersegener shaft, while fine crystals of galena occur in some of the others. The ores are associated with clay slate, grauwacke, and heavy spar. Deep down, but only in the Rosenhöfer Mine, blende is found accompanying lead ores; but this does not occur in the upper part of the lode.

The most important of the Clausthal veins occurs in the Burgstädter group, and seldom has any lode been richer in massive lead ores. The occurrence of solid galena is specially to

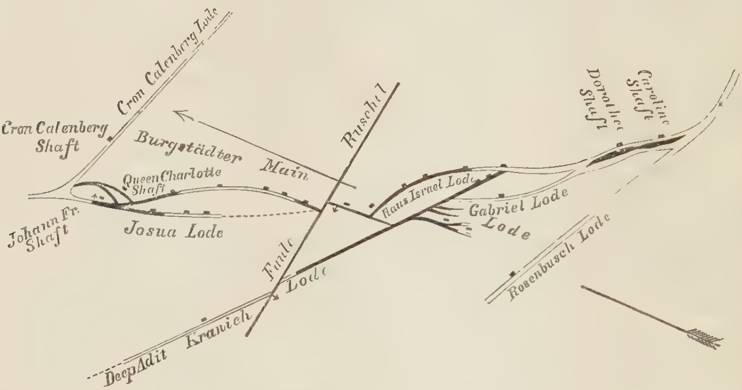


FIG. 88.—Burgstädter lode-group; horizontal section.

be noted at two points, namely, in the Dorothee Mine and in the Herzog Georg-Wilhelm Shaft.

Fig. 88 represents the Burgstädter lode-group, from which it will be seen that it is not a single vein, but is associated with several others, although no distinct network is present as in the Rosenhöfer ground. At the north-western end of the Burgstädter Lode, the Cron-Calenberger Lode occurs, and at this point also originates the Zellerfelder main-lode with its variable branch veins. It may be assumed that the Cron-Calenberger Vein has essentially been filled by infiltrations from the Zellerfelder lode fissure, and that the galena in the vicinity of the Ring Shaft has originated from this lode. The Ernst-August Mine is at present the most westerly on this course, and in this extended lode the contents vary considerably, the galena being accompanied by clay slate, grauwacke, calc spar, quartz, a little spathose iron ore, copper and iron pyrites, and, deeper down, by blende. It is noteworthy that the ore in the eastern portion is associated with clay slate and grauwacke; in that to the west of this, compact calc spar occurs, while still further west the lode becomes more quartzose, the Gabriel Lode being specially rich in quartz. Although galena is the ore chiefly raised, yet in the Königin Charlotte Mine the ore is not galena but copper pyrites.

In the Zellerfeld mines the quartzose character of the lode is still more marked. There is, however, another circumstance to be noted which is very characteristic of the Ring and Silberschnurr Mine. Here the galena, in certain parts of the lode, occurs in annular and polygonal forms which enclose parts of the gangue and country rock. The whole face of the lode is often covered, as it were, with different figures, and the enclosed fragments of rock are all of the same kind, although they often differ in colour, structure, and density. As these figures usually approximate to rings, it may be assumed that the mine has acquired its name from this circumstance.

In the Schulenberger and Bockswieser group, ore is found in two zones only, which are tolerably distant from one another, namely, to the east near Schulenberg and Festenburg, and to the west near Bockswiese.

The following remarks apply not only to these lodes but to all those of the Upper Harz generally:—

If the contents of a lode are soft and easily weathered, a depression commonly results along its outcrop, as in the Charlotte Lode near Wildemann. Sometimes, however, clay is formed by the weathering of the veinstone, and this, being impervious, gives rise to a swamp. If the contents of a lode are quartzose and less easily disintegrated than the country rock, then the weathering causes the lode to project from the surface of the ground like a wall. This may be well seen at different spots on the Schulenberger and Bockswieser group. Here the lode presents another peculiarity, which is characteristic of the Herzog, August, and Johann-Friedrich Mines, namely, that the veinstone of the western part of the lode is essentially softer than that of the eastern portion.

The celebrated mining district of St. Andreasberg [1] is situated on the southern edges of the Rehberg and Sonnenberg, on the south-west end of the Brocken mass of granite; the lodes being enclosed in a narrow zone of Silurian clay slate and grauwacke

[1] H. Credner, *Zeit. d. d. geol. Gesellsch.* xvii. 1865, p. 163. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd ed. ii. p. 90.

bounded on the north by granite and on the south by diabase. According to Langemann,[1] however, the age of the country rocks is that of the lowest horizon of the Devonian. The lodes are in some cases destitute of ore, while in others they contain ores of silver, iron, or copper. The barren veins often attain a width of above 180 feet, and are filled with fragments of clay slate and clay; they dip from 55° to 75° towards the south, and extend a great distance on the line of strike. Two of these barren veins, the Neufanger towards the north, and the Edelleuter towards the south, enclose a horse or long ellipsoidal mass of rock, consisting principally of clay slate, above 2,500 fathoms in length, and more than 500 fathoms in width. On one side of this large enclosure of country rock is the Edelleuter vein, or flucan, which continues in nearly a straight line, while the Neufanger vein forms an arch on the other. Within this space only are silver lodes ever found, and they do not extend beyond the enclosing veins. All the lodes known at St. Andreasberg outside this space contain, with but few exceptions, only iron ores and copper pyrites.

Two systems of silver lodes are distinguished according to their direction. The first is composed of several lodes which strike N. 22° to 37° W., and dip at a great angle towards the north-east. The most important of these are the Franz-August Lode, the Samson Lode, and the Jacobsglück Lode. Two lodes only belong to the second system, namely, the Gnade-Gottes and the Bergmannstrost Lodes, which strike nearly parallel to the limiting flucan, and dip 60° to 85° north. The silver veins are not very large, few of them being above eighteen inches in width. The principal gangue is calc spar, and the most important ores are galena, antimonial and arsenical silver ores, and native arsenic; these are accompanied by apophyllite, harmotome, desmine, stilbite and fluor spar. The silver lodes cross and frequently dislocate one another, but calcite is always the most abundant gangue. The iron lodes outside the enclosed ellipsoid of country rock are filled with compact red iron ore, and with several veins of copper pyrites and cobalt ores, from a zone parallel to the edge of the granite.

The presence of zeolites, the comparative scarcity of galena, and the predominance of rich silver ores, characterise the St. Andreasberg lodes and distinguish them from those of Clausthal, in which galena is abundant and the other minerals do not occur. Some of these lodes have a very regular banded or combed

[1] *Zeitsch. f. Berg. Hütt. u. Salinenwesen*, 1891, xxxix. p. 47.

structure, and it would appear that their origin is in some way intimately connected with the intrusion of the neighbouring diabase. Many of the minerals present, such, for instance, as cerargyrite, tinder ore and ganomatite, are evidently products of the decomposition of other substances. The Samson Lode has been worked and found to be productive to a depth of 800 metres (2,624 feet), although on account of the limited extent of the ore ground it has been followed horizontally for a distance of about 2,100 feet only.

In the district of Harzgerode and Neudorf,[1] which is of considerable interest to the mineralogist, the lodes are principally enclosed in clay slates of Silurian age. This is especially the case in the Meisenberg and Pfaffenberg, where their strike is south-east and north-west parallel to the principal axis of the Harz. The veinstone consists of quartz, spathic iron ore, and calcite, with which are associated galena, iron and copper pyrites, tetrahedrite, bournonite, stibnite, and occasionally traces of wolfram. These lodes also frequently contain fragments of country rock, which are often surrounded by concentric layers of different ores in the following order, namely, spathic iron ore, quartz, finely granular galena, dark brown blende, coarsely granular galena. Zinken has described some of the mineralogical peculiarities of these veins, particularly those belonging to the Birnbaum group, and has pointed out that in some places the fissures, instead of having become filled with ordinary veinstone, contain only clay slate traversed by numerous small branches. In the clay slate these small veins consist of quartz, but when the wall rock is composed of porphyry they are filled principally with galena. In the year 1879 Neudorf produced 1,414 tonnes of lead ore of the value of £7,417.

The Rammelsberg[2] is a mountain on the northern borders of the Harz, nearly two English miles south of the town of Goslar, the summit of which is 2,076 feet above the sea level. The rock consists of three members of the Devonian formation, namely, the Goslar slate, formerly called Wissenbach slate by F. A. Römer, the Calceola slate, and the Spirifer sandstone. These rocks lie above one another in reversed order, so that the Spirifer sandstone forms the summit of the mountain;

[1] Credner, *Geogn. Verhaltn. Thuring. u. d. Harz*, 1843, p. 123. Zinken, *Leonhard's Jahrbuch*, 1850, p. 692. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, ii. p. 89.

[2] F. Wimmer, *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxv. 1877, p. 119.

beneath this comes the Calceola slate, and lastly the Goslar slate. The characteristic cleavage of the Goslar slate is not usually met with at the Rammelsberg, as the cleavage and stratification coincide; the interstratified limestone and quartzite being parallel with the strata containing fossils. When the plane of stratification of the slate has a dip greater or less than 45°, traces of cleavage may be again remarked, particularly to the north-west of the Winterthal.

The Rammelsberg ore deposit consists of an aggregation of irregular lenticular masses of ore of varying dimensions, its greatest extension in the direction of the strike being 655 fathoms, and its usual thickness from 45 to 60 feet, which sometimes, where the ore mass separates into two branches, extends to above 90 feet. Like the country rock it has a strike towards east-north-east and west-south-west, with a dip 45° south-east following all

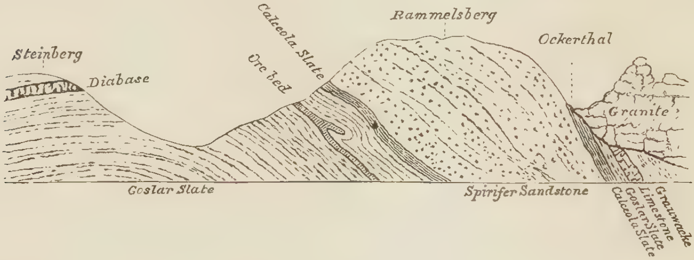


Fig. 89.—Section across the Rammelsberg.

its contortions. The Rammelsberg ore deposit is consequently a true bed, and an independent member of the Goslar slates.[1]

Fig. 89, representing a transverse section across the Rammelsberg, and Fig. 90, a section on a larger scale across the ore bed, will serve to show the mode of occurrence of the ores in this mine. This figure should be compared with Fig. 65, page 183, which shows the result of modern investigations.

This deposit was regarded by Delius (1770) as a stockwork, and was described by Lasius (1789) as being neither lode, stock, nor stockwork, but as a "rhomboidal parallelopipedon of ore." Böhmer (1793) called it an *Erzflötz* or ore-bed, and the branch he considered a true lode. Reichetzer (1821) calls it a *stehender Stock;* B. v. Cotta calls it a *liegender Stock*, or recumbent mass, while Gatterer and Hausmann regarded it as a bed. Recent

[1] The above statements, descriptions and accompanying sections have been here retained as possessing a historical interest when compared with the views at present current respecting the true character and genesis of this deposit.—H.L.

searching investigations have brought out a number of points hitherto overlooked, and the above views respecting the constitution and mode of origin of this deposit are no longer generally

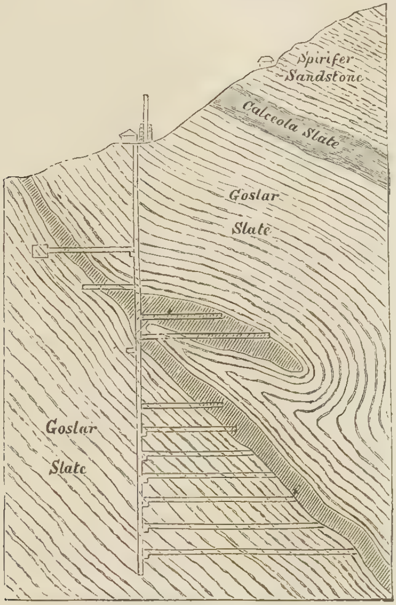


FIG. 90.—Section across the ore bed, Rammelsberg.

held, most geologists now looking upon the deposit as an epactic one. The opinions given on page 183, which are in the main those of J. H. L. Vogt, are now pretty generally accepted.

This bed is composed of lenticular aggregations of sulphide ores, which consist of compact masses of

1. Galena with blende and iron pyrites.
2. Galena with heavy spar.
3. Copper and iron pyrites.

The minerals of the Rammelsberg ore-bed may be divided into three classes :—[1]

a. Minerals which originally formed the deposit.

b. Minerals which occur in fissures and veins in the ore-mass.

c. Minerals which have been formed by the decomposition of the two preceding.

a.—Of this class the prevailing constituent is iron pyrites. Copper pyrites, always mixed with iron pyrites, and sometimes with fahlerz, is also present. Galena occurs in a compact form,

[1] F. Ulrich, *Die Mineralvorkommnisse in der Umgegend von Goslar*, 1860.

but when mixed with pyrites it constitutes the so-called *melirten Erze*; when in association with blende, iron pyrites, and heavy spar, it forms lead ore proper, which is called "brown ore" or "gray ore," according as blende or heavy spar predominates. Blende occurs in compact masses, as does also heavy spar; quartz is exceedingly rare.

b.—In class *b*, copper pyrites is found in beautiful crystals, crystallised fahlerz and galena also occurring, while the blende is usually compact. The heavy spar is crystallised, and filling the fissures are found calcite, calamine, gypsum, spathic iron ore and quartz.

c.—A number of interesting secondary minerals are being formed in the ancient workings of the Rammelsberg Mine by the decomposition of the original ores. Among these sulphate of iron, rarely crystallised but often in a stalactitic form, is of frequent occurrence, as are also botryogen, rœmerite, voltaite, copiapite, and vitriol ochre. Sulphates of copper, zinc and calcium are also present, as is also *hair-salt*, a magnesium aluminium sulphate containing sulphates of zinc and iron.

Professor G. Köhler[1] of Clausthal has brought forward additional evidence (now however discredited by later studies of Vogt and others) of the correctness of the view that the Rammelsberg deposit is a true ore-bed, and an independent member of the Goslar-slate series, and in his paper on this subject gives drawings of a number of specimens of the ores, showing that all the contortions of the surrounding rocks are shared by the ore-bed itself.

According to official returns the production of the principal mines of the Harz, during the year 1881, was as follows:—[2]

Mines.	Lead ores.		Copper ores.		Zinc ores.	
	Weight.	Value.	Weight.	Value.	Weight.	Value.
	Tonnes.	£	Tonnes.	£	Tonnes.	£
Clausthal	10,147		424 (Clausthal and Lautenthal)	1,752 (Clausthal and Lautenthal)	493	16,435 (Clausthal and Lautenthal)
Lautenthal	1,758				5,238	
Silbernaal	4,146	200,752 (Clausthal to St. Andreasberg)				
St. Andreasberg	109					
Rammelsberg	27,547	11,143	19,365	28,087		
Totals	43,707	211,895	19,789	29,839	5,731	16,435

[1] "Die Störungen im Rammelsberger Erzlager bei Goslar," *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxx. 1882, pp. 31 and 278.

[2] *Ibid.* xxx. 1882, pp. 175, 186. *Ibid.* xvii. 1869, p. 259. *Ibid.* xix. 1871, p. 224.

In addition to the above, Andreasberg produced, during the year 1881, 122 tonnes of silver ore of the value of £5,901.

Inclusive of cupriferous lead ores and iron pyrites, the production of Rammelsberg in 1881 amounted to 46,990 tonnes.

In 1894 [1] the results obtained in this district were :—

Mines.	Lead ores.		Copper ores.		Zinc ores.	
	Weight.	Value.	Weight.	Value.	Weight.	Value.
	Tonnes.	£	Tonnes.	£	Tonnes.	£
Clausthal	5,929	85,250 (Clausthal, Lautenthal, Grund, St. Andreasberg together)	401	1,264	6,878	44,487 (Clausthal and Lautenthal together)
Lautenthal	1,551		8	32	5,586	
Grund	4,943		—	—	—	—
St. Andreasberg	509		—	—	—	—
Rammelsberg	33,613	13,737	21,133	21,780	—	—

In addition to the above, the United Samson Mines of St. Andreasberg produced 6,309 tonnes of raw silver ores, which were dressed down to 6·376 tonnes of rich ore worth £1,856; the 509 tonnes of (dressed) lead ore mentioned in the table were produced from 3,168 tonnes of raw ores and valued at £3,090. The Rammelsberg mines also produced 506 tonnes of pyrites, bringing their total output to 55,473 tonnes of ore valued at £35,963. The metals produced in the smelting works of the "Communion Harz Verwaltung" in 1894 [2] were as follows :—

Lead	5,031 tonnes,	value £44,738
Copper	1,191 ,,	,, 52,821
Silver	7,824 kilogr.	,, 34,560
Gold	76·3 ,,	,, 10,682

Mining was commenced in the county of Mansfeld,[3] on the southern declivity of the Harz, in the year 1199, and has, with but little interruption, continued flourishing up to the present time. In the fifteenth century about 1,000 tons of copper were annually produced, but, during the sixteenth, mining was for some time interrupted by the Thirty Years' War. Working was, however, resumed in 1573 by the Elector of Saxony, since which time operations were continuously carried on by independent companies. In 1852 these companies were all consolidated into the "Mansfelder Kupferschieferbauende Gewerkschaft" (Company for work-

[1] *Zeitsch, f. Berg. u. Salinenw.* xliii. 1895, pp. 146, 147, 153.

[2] *Ibid.* xliii. 1895, p. 178.

[3] *Der Kupferschieferbergbau und der Hüttenbetrieb zur Verarbeitung der gewonnen Minern,* 1881.

ing the Mansfeld Copper Schist), which now produces annually about 15,000 tonnes of copper, together with 75 tonnes of silver, and affords employment to nearly 13,000 miners.

It is interesting to note that this was the first place in Germany where steam power was applied to mining purposes. In the year 1785 it was found impossible to keep down the continually increasing quantities of underground water (then reaching 2 cubic metres = 70 cubic feet per minute) by means of the horse power that had up till then been employed, and a Watts' "fire-engine" was accordingly imported from England, by which the pumps were driven with complete success.

The geological constitution of the copper-mining district of Mansfeld is, on account of the regularity of the stratification, exceedingly simple, and, with the exception of melaphyre, which occurs sparingly in the Wipper Valley and a few adjacent localities,

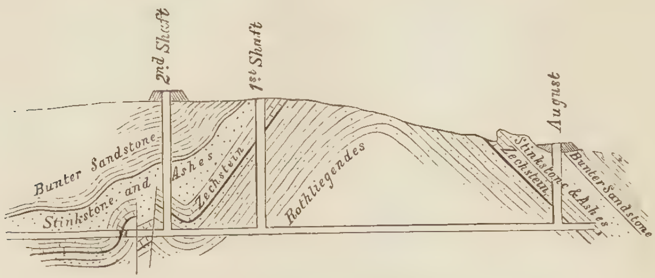


FIG. 91.—Section of the strata, Tiefthal.

the whole region is composed entirely of stratified rocks, of which the *Rothliegendes* forms the lowest member.

Fig. 91, representing an anticlinal in the Tiefthal district, will convey a correct idea of the position of the various strata. Upon the whole the strata here form a comparatively regular basin, round the edge of which the copper schist crops out for the greater part of its circumference; its width is about 11 miles and its area about 193 square miles. Most of the present workings are restricted to the northern and western sides of the basin, where the copper schist occurs with a flat dip of from 5° to 8° over a length of about 14 miles.

The *Rothliegendes*, the name applied by the miners to the sandstones and conglomerates forming the base of the Mansfeld *Kupferschiefer*, or copper schist, sometimes exceeds 500 fathoms in thickness, and exhibits many characteristic peculiarities, by means of which it is easily recognised. This formation may be divided into three zones, the lower, the middle, and the upper. The lower of these divisions is characterised by a conglomerate of waterworn hornstone pebbles; the second by various beds of carbonate of lime; and the third by a sharp angular grit much employed as a material for millstones.

The *Weissliegendes* may be considered as the uppermost bed of the *Rothliegendes*, for, although this stratum, four feet six inches in thickness, resembles to some extent the layer above, particularly in its grayish-white colour, in the presence of carbonate of lime, and in its containing in its upper beds ores of the same metals as the limestone formation above, it still retains the peculiar sandstone character possessed by the *Rothliegendes*.

As a rule, the *Weissliegendes* lies on the upper clayey beds of the *Rothliegendes* as a grayish-white bed rich in mica and lime. Above this follow beds of sandstone, which possess a cementing material of a grayish-white colour rich in lime, together with, in places, beds of conglomerate containing fragments of quartz and siliceous slate. The upper bed of this sharply characterised division becomes, through the disappearance of lime as a cementing material, very rich in quartz, and in places takes the appearance of hornstone.

The *Zechstein* formation at Mansfeld consists of two principal divisions, an upper and a lower. Of these the lower comprehends the *Kupferschieferflötz*, or cupriferous seam; the *Dach*, or roof, and the *Zechstein* proper; while the upper consists of the *Rauchwacke, Rauhstein, Stinkstein,* and *Asche* with gypsum and various clays.

The bituminous marl constituting the copper schist, or copper shale, lies everywhere with the greatest regularity on the *Rothliegendes*, so that it can be followed as a thin black band; indeed in some places, such as at the southern edge of the Harz, it even stretches beyond, which appears the more remarkable when its small thickness, only about nineteen inches, is taken into consideration. The bituminous contents of the copper-bearing bed, which, however, diminish near the top, are more characteristic than even its metallic contents, as bitumen is often present when copper ore is absent, or occurs only in quantities too small to pay the expenses of smelting.

Even on a cursory examination, without taking into consideration the greater or less proportion of copper present, the copper schist is readily divisible into several distinct layers. The deposit is most complete in all its members in the Hettstedt and Gerbstedt districts; but this is less the case in the districts of Eisleben and Sangerhausen.

The different layers of the copper schist receive from the miners the following names, and occur in the following order, beginning at the bottom.

Hettstedt, Gerbstedt.	Eisleben.	Sangerhausen.
9. Oberberge.	Dachberge.	Noberge.
8. Noberge.	Noberge.	
7. Lochberge.	Kopf {Ober, Unter}	Unterwand.
6. Kammschale.	Kammschale.	Schieferkopf.
5. Kopfschale. 4. Schieferkopf {Ober, Unter}	Grobe Lette.	Blattschiefer.
3. Lochschale.	Feine (Loch) Lette.	Schramschiefer.
2. Lochen. 1. Liegende Schale.	Wanting.	Erzschiefer.

The first division consists of the *Liegende Schale*, which is not everywhere present, after which comes the *Lochen*, consisting of a soft clayey bed, which generally lies on, and is firmly attached to, the layer of shale below; whilst above it is the *Lochschale*, chiefly distinguished by its extremely fine lamination. The entire lower division is at the most from 2 to 2¼ inches in thickness.

The second division is much coarser than the first. The *Schieferkopf*, which is divided into lower and upper, has a solid homogeneous appearance, which, however, it loses in the *Oberkopf*, which is coarser and shows an uneven fracture. This is followed by a thin layer, the *Kopfschale*, which sometimes contains strings of gypsum, though by no means with the same regularity as is seen in the next layer, the *Kammschale*.

The *Kammschale* presents a very characteristic appearance, and is everywhere readily recognisable. It is traversed by fine regular threads of gypsum, which gives it an appearance well described by the miners as "white haired." The entire second division (4, 5 and 6) reaches a thickness of only four inches.

Much coarser, but still almost always with a distinct cleavage, is the *Lochberge*. The cross fracture is perceptibly grayer and paler than is that of the preceding layers. The *Lochberge*, being separated from the strata both above and below by smooth schistose surfaces, separates in a layer 2½ to 4 inches in thickness, and is often used as a building stone.

The *Noberge* is still finer schist, of less clearly defined texture, in which bitumen is less readily discerned.

The *Oberberge* is gray, and already exhibits characteristics very similar to those of the layer above known as the *Dach*; the *Noberge* and *Oberberge* together attain a thickness of from 6 to 8 inches.

The lower portion of the series is, in the Eisleben district, always known as the *Lette*, and in that of Sangerhausen the layers of the lower division are usually soft, plastic and greasy; when firmer they often contain visible grains of pitch. The *Erzschiefer*, so called on account of its greater metallic contents, is not everywhere present, and when present does not exceed a thickness of ⅓ inch.

The *Dach* exhibits a coarse fracture and is not readily fissile, being usually a grayish-white compact bed of marly limestone from 6 to 14 inches in thickness, which on exposure to the air becomes yellowish-brown, and, on weathering, separates into polygonal fragments.

The *Faüle*, from 2 feet 6 inches to 3 feet in thickness, is a dark-blue solid limestone which is always distinctly marly.

The *Zechstein* proper is a dense yellowish or smoke-gray limestone with a conchoidal fracture, and is the most regular and continuous of all the strata accompanying the *Kupferschiefer* seam. It is in a high degree suitable for building purposes, since it not only occurs in regular beds, varying from 4 to 12 inches in thickness, but is also readily divided into parallelopipedal blocks. Flat lenticular bodies enclosing a dark carbonaceous mass as a kernel, probably the remains of some organism, are peculiar to the *Zechstein*. The upper layers, from 6 to 12 inches thick, are porous, the pores being of a yellow colour. This bed passes into the next of the series known as the *Rauchwacke*, which, in some districts often of considerable thickness, is in the Mansfeld district only from 18 inches to 6 feet thick, and lies on the top of the *Zechstein*; but it is seldom of great extent, thinning out and disappearing and then again appearing. It passes from a firm dark-grayish black dolomitic limestone to a yellowish-gray or yellow magnesian marl.

The *Rauchwacke* is often traversed by small fissures filled with calcite, which imparts to the rock the appearance of a breccia of which that mineral is the cementing material.

The *Asche*, which consists of a gray earthy or sandy dolomitic marl, is never absent from the top of the *Zechstein*, but is extremely variable in thickness, and is often much intermixed with other beds.

The *Rauhstein*, which is never absent where the *Asche* is present in considerable quantity, forms an intermediate link between the *Rauchwacke* and *Asche*. It is blackish-gray in colour and resembles the *Rauchwacke* in its porous structure and the irregular arrangement of its constituents. It is usually found embedded in the *Asche*. *Stinkstein*, from its frequent passage into the *Asche*, with which it intermingles as frequently as does the *Rauhstein*, is closely allied with these two beds. It is of a dark-gray colour and thinly fissile, the planes of division, however, being in very varying directions, owing to movements having taken place in the beds which appear to have broken the stratum and thus disturbed the foliation. The peculiar odour of the *Stinkstein* is shared to some extent by the upper layers of the whole series.

The blue clay, which forms the topmost layer of the formation, is often interstratified with red clay, and encloses layers of *Stinkstein* and *Rauhstein*. The blue clay passes into *Asche*, becoming more sandy in so doing.

Gypsum and anhydrite play an important part in the *Zechstein* formation, penetrating all the layers down to the *Weissliegendes*, and varying from scarcely visible traces to distinct beds of greater or less thickness; almost everywhere where deposits of this mineral are bored through, anhydrite is found somewhere in the mass.

The metalliferous contents of the *Kupferschiefer* seam occur as a rule in the form of *Speise*, that is, sprinkled in the condition of very fine dust which, on a transverse fracture, causes a metallic reflection in sunlight. It has either a golden colour from the presence of copper pyrites in predominant quantity, or a violet, blue, and copper-red colour from the presence of erubescite; more rarely the colour is steel-gray from copper glance, or grayish-yellow from iron pyrites, and, finally, sometimes bluish-gray from the presence of galena. Although the *Speise* principally consists of sulphuretted ores of copper, there also occur, in greater or less quantities not visible to the eye, sulphide of silver, blende, galena, iron and copper pyrites, copper-nickel and arsenide of cobalt, as well as compounds of manganese, molybdenum and selenium; oxidised compounds and salts also occur as secondary products. In addition to the *Speise* small bands and filaments of the same ores likewise occur, filling fissures parallel to the bedding; the presence of these is not, however, sufficient to make the ore profitable for smelting when *Speise* is absent. None of the layers of the *Kupferschiefer* seam are barren of metal, but it is only in a few of the bands that it occurs in workable quantities, these being invariably the lower layers up to the *Kammschale*, which is, as a rule, the limit of smeltable ore.

At Eisleben the *Lette*, together with the *Kammschale*, are, as a rule, the productive beds, and with these is associated the *Schieferkopf*, especially on the ridges and in the hollows of the seam. In proportion as the depth increases, however, the clay or the *Kammschale* frequently becomes too poor for smelting. In the Hettstedt district the productive slate is confined mainly to the *Lochen* and *Unterkopf*, the *Oberkopf* being mostly unproductive, while *Dachberge* worth smelting occurs but rarely.

The term *Flötz*, seam, is usually applied to the productive bed only, the thickness of which varies from 2½ to 5 inches. With this restricted height it is of course necessary to remove a portion of the country rock in order to allow room for working. As the floor is hard the roof is removed to such an extent as to allow the hewer to work in a reclining position, and as the miner reclines on his side the breadth of the shoulders is the minimum height of the working space necessary. The most suitable height is about twenty-two inches, but the cupriferous band is often worked with a height of from sixteen to eighteen inches only.

In some places there occurs below the *Kupferschiefer*, on the upper part of the *Weissliegendes*, a deposit known as *Sanderze*, which usually appears as what is locally known as *gelbe Tresse*, consisting of consolidated grains of copper pyrites mixed with sand. Wherever this *Tresse* appears, it assumes the form of a golden yellow band of from one-third of an inch to one inch. The *Kupferschiefer* of the Mansfeld district contains on an average from two to three per cent. of copper with about ten pounds of silver to the tonne of copper, whilst the *Sanderze* of the Sangerhausen district reaches as high as five per cent. of copper when the ore is pyrites, to ten per cent. when it consists of erubescite, the silver in this case reaching only five pounds per tonne of copper. In the northern portion of the district the schists are poorer in copper, yielding scarcely one and a half per cent.

Up to the year 1862[1] there had been practically no work done below adit level, but deep shafts were commenced in that year, and since 1864 a number of important ones have been sunk, the

[1] M. Przyboski, "Der Kupferschieferbergbau u. die Hüttenproduction im Mansfeldischen," *Berg. u. Hüttenmännisches Jahrbuch*, 1889, xxxvii. p. 41.

deepest being the *Ernst Schact III.*, 375 metres (1,230 feet) and the *Otto Schact III.*, 367 metres (1,204 feet). In 1890 there were over thirty shafts down, fourteen of which were used for winding.

The following analyses give the composition of copper schist during the second quarter of 1879 :—

	Otto Shaft.	Ernst Shaft.	Gluckhilf Shaft.
Silica	38·42	33·15	29·22
Alumina	15·93	12·90	11·76
Lime	10·93	14·39	12·66
Magnesia	3·53	2·32	2·25
Carbonic acid	7·02	10·47	9·43
Iron	1·81	3·31	2·97
Copper	2·01	2·90	2·88
Silver	0·015	0·016	0·021
Sulphur	3·18	2·15	4·97
Bitumen by loss	14·63	9·89	17·21

Zinc, lead, manganese, nickel, and cobalt were not quantitively estimated.

As shown in Fig. 91, the *Kupferschiefer* deposit is overlain by the well-known Bunter Sandstone, which, in this district, consists of red slaty clays, red-coloured sandstones and sandy shales, oolitic beds and thick masses of gypsum. Copper schist is also worked in Hesse, and at Saalfeld in Thuringia. Some idea of the importance of the Mansfeld metalliferous deposits may be gathered from the following facts. The total number of men employed at the end of 1881 in all departments, mining, transport, smelting, &c., was 13,087, and, taking their families into consideration, the total number of persons dependent on the working of the *Kupferschiefer* was a trifle over 35,000. There does not seem to have been much variation since that period, the number of men employed in 1894 being returned as 12,954.

In the Mansfeld district the following quantities of copper schist have been raised since 1862 :—

Year.	Tonnes.
1862	61,971
1865	91,028
1868	135,284
1871	170,580
1874	192,847
1877	269,482
1878	299,601

Year.	Tonnes.
1879	320,320
1880	394,650
1881	436,048
1882	490,211
1883	536,084
1884	522,175
1885	557,185
1886	441,373
1887	443,060
1888	469,747
1889	511,337
1890	536,489
1891	521,687
1892	523,000
1893	514,190
1894	521,259

Besides this the Sangerhausen district, belonging to the Mansfeld Company, produced 138,405 tonnes of copper schist during the period from 1862 to 1880 inclusive; or an average of 7,284 tonnes per annum.

Sangerhausen alone, in 1880, produced 10,933 tonnes.
" " 1881 " 9,367 " [1]

Altogether, Sangerhausen and Mansfeld, in 1880, produced 405,583 tonnes, representing a value of £537,390; and in 1881, 445,415 tonnes, worth £660,487. In the year 1881 the quantity of silver and copper obtained [2] was as follows:—

Copper	10,999 tonnes.
Silver	59,836 kilogr.

In 1894 [3] the *Mansfeldsche Kupferschieferbauende Gewerkschaft* produced 521,259 tonnes of ore, valued at £779,850; this yielded:

Copper	15,217 tonnes, value	£653,218.
Silver	75,496 kilogr. "	£321,235.

So that the produce of the smelting works for that year was close upon a million sterling.

In recent years large works have been undertaken with the

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.*, xxx. 1882, p. 183.
[2] *Ibid.* xxx. 1882, p. 226.
[3] *Ibid.* xliii. 1895, pp. 151, 177.

object of draining the lake that covers a considerable area of the copper-bearing district, the waters from which, soaking through the ground into the mines, have proved a great source of expense in working, and a serious obstacle to their further development.

The iron ores of the Harz,[1] which are very widely distributed, chiefly consist of hæmatites and limonites, although both magnetite and spathic iron ore are also occasionally met with. B. v. Cotta remarks that the comparative rarity of magnetite may probably be explained by the absence of crystalline schists, since it is principally in such rocks that deposits of iron ores have become changed into magnetite by the metamorphic action which has caused the alteration of the rocks themselves. In the Harz, as in numerous other localities, iron ores are for the most part associated with igneous rocks, either being enclosed within them, or forming contact deposits in their immediate vicinity. They occur usually, but not universally, in connection with diabase, and are found in the form of beds, veins, and irregular deposits.

Many of the masses of greenstone penetrating the Silurian rocks of the Eastern Harz, near Tilkerode, contain deposits of hæmatite, which, according to Zinken, do not extend into the surrounding clay slates. They occur either as irregular lodes in the diabase, or form deposits between it and the neighbouring slate, and it is remarkable that, in addition to iron ores, they sometimes contain various compounds of selenium, such as clausthalite, lehrbachite, and tilkerodite associated with auriferous palladium. As is usually the case, when spathic iron ore is present it has, near the surface, been converted into limonite. Similar deposits occur at Elbingerode, Lehrbach, and Zorge; while on the Krokenstein, near Hüttenrode, hæmatite forms a contact deposit between limestone and clay slate. Little appears to have been done during late years either at Tilkerode, Zorge or at Lehrbach. During the year 1881 Elbingerode produced 4,600 tonnes of brown iron ore and 2,173 tonnes of red hæmatite. In 1894 the chief mines of the district were those of Bülten and Adenstadt, belonging to the Ilseder Company, which produced 276,423 tonnes of ore entirely from openworks, whilst the whole Elbingerode district only produced 3,140 tonnes.

The manganese deposits of the Harz are almost exclusively confined to the neighbourhood of Ilfeld, where they occur in porphyrite in the form of veins varying from a few inches to nearly two feet in width, and of which the usual strike is between N. 82° W. and N.

[1] Zinken, *Der östliche Harz*, i. 1825, p. 135; Credner, *Geogn. Verh. Thür. u. des Harzes*, 1843, p. 127; Kerl, *Berg. und Hüttenm. Zeit.* 1853, p. 148.

30° W. The ores, which are in part compact and in part crystallised, consist of manganite, pyrolusite, varvicite, braunite, hausmannite, psilomelane, and wad; the associated matrix consisting of calc spar, heavy spar, brown spar, and, sometimes, carbonate of manganese, with crystals of calc spar coloured black by manganic oxide. These lodes are invariably accompanied by branches in which ores of manganese occur in a compact form and without any admixture of matrix. They are seldom productive to a greater depth than about six fathoms, although in a few exceptional cases they have been followed to beyond thirty fathoms. The porphyrite of Ilfeld is in some places traversed by lodes of iron ore.

During the year 1881 the Ilfeld mines produced 144 tonnes of manganese ore of the aggregate value of £1,315.[1] The manganese mines were closed in 1891, but the district still continued to produce a certain amount of iron ore. In 1894 the output was 781 tonnes of brown and 4,400 tonnes of red hæmatite.

THE THURINGIAN FOREST.[2]—Iron ore was at a very early period worked in the Thuringian Forest, iron works having been built near Saalfeld in 1017. Gold was mined at Goldisthal in prehistoric times, while the gold washings and gold mines at Reichmannsdorf and Steinhaide, near Saalfeld, were flourishing in 1209; they were, however, abandoned in 1430, but resumed in 1533. The Güte-Gottes Mine at the Petersberg, from 1576 to 1580, yielded about seventy-five pounds of fine gold. It was abandoned in 1635 on account of the Thirty Years' War, but in 1692 was resumed by foreign miners procured by Duke Albrecht. In the year 1700 there were gold-washings on the Werra and the Ilz near Schwarzenbrunn and Schalkau, but they do not appear to have been successful. The only ores at present obtained in this region are those of iron and manganese, with a little antimony and a still smaller quantity of copper ore.

Geologically, the Thuringian Forest is divided into two portions of very unequal areas. The south-eastern part, which joins the plateau of the Fichtelgebirge, and from which it is separated by no natural boundary, consists, principally, of Silurian rocks bounded on the north by Permian strata, and on the south-west by rocks of Carboniferous, Permian, and Triassic age. This district is penetrated by but few masses and dykes of granite or other eruptive rocks, and is by no means rich in metalliferous veins.

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.* 1882, *et seq.*

[2] Krug von Nidda, *Karsten's Archiv.* xi. 1838, p. 13. Credner, *Geogn. Verhält. Thuring. u. d. Harz*, 1843, p. 130.

The north-western portion consists of a small mountain ridge, of which the geological characteristics are much varied. Here granite, syenite, gneiss and mica schists appear to be the oldest rocks and are frequently traversed by various porphyries and greenstones. In the Silurian rocks of the south-eastern district considerable quantities of hæmatite and limonite are mined, particularly in the neighbourhood of Steinach and at Schmiedefeld, near Gräfenthal, where a bed of iron ore courses parallel to the strike of the enclosing slates.

At Weitisberga, near Lehesten, in the vicinity of a mass of intrusive granite, are several lodes which appear to occur in small masses of greenstone which penetrate the slates, but are not found in the slates themselves. These veins contain small quantities of galena, blende, and copper pyrites, intimately intermingled with a gangue consisting, principally, of calcspar and hornblende.

The small intrusion of granite, which comes to the surface between various masses of porphyry near Schmiedefeld contains at the Krux Mines, west of the village, some irregular deposits of iron ore; the surrounding rock, which is hornblendic granite, appears to be associated with a sort of greenstone. The most important of these deposits is that known as the Schwarze Krux, sometimes consisting of nearly pure magnetite, but occasionally more or less mixed with quartz, garnets, iron pyrites, copper pyrites, mispickel, specular iron ore and fluor spar. The Rothe and the Gelbe Krux, near the Schwarze Krux, contain somewhat similar deposits, which consist partly of hæmatite and partly of magnetite, often, however, much mixed with iron pyrites.

The quartz-porphyry, as well as the mica-traps and melaphyres of the Thuringian Forest, is sometimes traversed by veins of oxide of manganese, whose strike is usually parallel to the trend of the mountain ridges. These lodes, which exceptionally penetrate the granite, consist of pyrolusite and psilomelane associated with calc spar and heavy spar; with these are found wad, hausmannite, braunite and, more rarely, manganite. The principal veins yielding ores of manganese occur in the Rumpelsberg and Mittelberg, near Elgersburg, where they usually occur without any considerable admixture of gangue. They are, however, sometimes associated with tabular heavy spar or calc spar, and the lodes not unfrequently enclose large horses of the rock in which they occur. When pyrolusite is present in a pure state, it usually forms bands parallel to the walls of the vein fissure with its crystals all directed towards the centre of the lode. The other ores of manganese are found in irregular patches, between the masses of country rock and clay, by which the lode fissures are partly filled. A few of the most important of these lodes attain a width of fifteen feet, while others can only be traced as mere lines. Their extreme depth has never been attained, although the workings on some of them have been carried fifty fathoms below the surface. The analogous deposits of pyrolusite in the neighbourhood of Ilmenau and Friedrichsroda are of less importance.

A dark-coloured slate which overlies the granite at Goldlauter, near Suhl, is of Carboniferous age, and contains thin layers of anthracite, together with impressions of ferns and stigmaria. One of the beds of this formation of a more than usually dark tint contains lenticular or ellipsoidal masses, varying from one inch to six inches in diameter, containing various metalliferous ores. These are arranged in concentric layers around a kernel generally consisting of sphærosiderite, although this is sometimes replaced by a fragment of black crystalline limestone. The kernel is usually surrounded by layers of copper pyrites, tetrahedrite, native silver, and a silvery white mineral (probably mispickel) which crystallises in fine needles and contains a large percentage of silver. A layer of reddish-brown spar, containing but slight indications of the presence of metals, surrounds the minerals above enumerated, and over this follow alternating bands of iron pyrites, mispickel, and argillaceous shale. These ellipsoidal masses are rarely so perfect as to exhibit in any one specimen the whole of the layers mentioned, and this deposit may be regarded as possessing greater geological interest than economic value.

In addition to iron ores, the *Zechstein* of the Thuringian Forest contains *Kupferschiefer*, with veins containing ores of silver and cobalt. The most important iron deposits of the *Zechstein* occur in the neighbourhood of Herges, and are worked in the Stahlberg, Mommel, and various other mines. That they originally consisted of spathic iron ore there can be little doubt, but they have now become chiefly converted into limonite. Although their form is irregular they have a general south-east and north-west strike and appear to be frequently connected with one another, but are entirely confined to the *Zechstein*. The strata of the *Zechstein* and Bunter Sandstone formations are much dislocated, and intrusions of granite and other eruptive rocks are of frequent occurrence. *Kupferschiefer* and *Weissliegendes* appear to be wanting in the neighbourhood of Herges.

In 1879 the Thuringian Forest produced 18,680 tonnes of iron ores value £5,914; 1,273 tonnes of manganese ores value £4,677; 41 tonnes of antimony ores value £746; and 10 tonnes of copper ores value £8.[1] Even this small output has decreased since then; in 1894 antimony mining had ceased, and only the two principal iron mines, Stahlberg and Mommel, were working steadily; the district produced 5,872 tonnes of iron ore in that year.[2]

The Saxon Erzgebirge.—This mountainous range constitutes an elevated plateau rising on an average from 2,000 to 2,500 feet above the level of the sea, with a gentle north-westerly slope towards Saxony and a more precipitous declivity in the contrary direction towards Bohemia. The predominant rocks of this region are gneiss and mica schists which, towards the north-west, gradually merge into non-fossiliferous clay slates.

These stratified rocks have been penetrated by numerous masses and dykes of granite, as well as by the so-called red gneiss; granitic and syenitic porphyry, together with various greenstones, are likewise of frequent occurrence. Basalt here and there forms small conical hills or appears in the form of dykes, while siliceous slates, covered for the most part by rocks of Carboniferous and Permian age, occur on the north-western declivity. The ore deposits of the Erzgebirge occur exclusively in crystalline schists and in igneous rocks, and although very numerous they are not exceptionally rich. They contain ores of silver, lead, zinc, copper, tin, cobalt, nickel, bismuth, antimony, arsenic, iron and manganese, with occasional traces of gold and mercury.

The veins of silver and lead ores, which also frequently contain ores of copper, are for the most part confined to a zone extending in a north-easterly and south-westerly direction over the crest of the mountains from Meissen, through Freiberg, Langenau, Oederan, Wolkenstein, Marienberg, and Annaberg, to Joachimsthal.

The tin-ore districts, which contain the oldest metalliferous deposits of this region, are found in groups which extend along the crest of the mountains, where they form lodes, impregnations, and surface deposits. Veins of cobalt and nickel ores, frequently containing bismuth, silver, lead and copper, occur chiefly in the neighbourhood of Schneeberg, but ores of cobalt and nickel are likewise found in the silver lodes of Freiberg, Marienberg, and Joachimsthal. Lodes of hæmatite and limonite, frequently containing manganese, lie chiefly within a zone corresponding to the crest of the mountains, but deposits of magnetite, associated with

[1] *Berg. und Hütten Kalendar*, Essen, 1882, p. 174.

[2] *Zeitsch. f. Berg. Hutt. u. Salinenwesen.* xliii. 1895. p. 130.

diabase and other greenstones, are distributed in groups throughout the Erzgebirge. Traces of cinnabar occur in the clay slates near Hartenstein, and ores of antimony, arsenic, and zinc, are found in numerous localities. Gold, although occasionally found in minute quantities, is no longer systematically sought after.

Mining operations in Saxony were first carried on at Freiberg;[1] some waggoners, who were transporting salt from Halle to Kuttenberg in Bohemia, having discovered pieces of galena on the road, carried them back to the Harz. This accidental discovery gave rise to mining, at what is now called Freiberg, by miners who, in 1160, emigrated from the Upper Harz. Mining was flourishing in 1181, but, owing to famine and religious wars, many of the mines were brought to a standstill in 1521. In 1540 the town of Freiberg already contained 32,763 inhabitants above the age of eleven years, the majority of the men being miners. Great difficulties were, however, experienced in draining the mines, so that in 1569 as many as 2,100 horses and 250 men were employed in raising water. In the beginning of the seventeenth century the richness of the mines was very great, and from the year 1529 to 1630, after subtracting the Government dues, they yielded a clear profit of £487,500. The Freiberg School of Mines was founded in 1702.

The lodes of Freiberg have been so carefully studied by B. v. Cotta, who passed a large portion of his life in the neighbourhood, and who may be regarded as the best authority upon this subject, that the following account is really little more than a *résumé* of his description of the veins of this region.

The ore district comprises the area lying between Nossen, Oederan, Ebisdorf, and the stream known as the Bobritzsch, consisting predominantly of gneiss, but which is towards the west overlain by mica schists and clay slates. These schistose strata are traversed by various eruptive rocks, some of which have become converted into serpentine. Both red and gray gneiss occur in the neighbourhood around Freiberg, and frequently alternate with one another in almost parallel layers. The stratification and foliation of these rocks are nearly horizontal, but they gradually fall away in two opposite directions so as to form a gently sloping saddle. The red gneiss is usually poor in lodes. The gray or normal Freiberg

[1] B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd ed. ii. p. 4. M. F. Gaetzschmann, *Die Aufsuchung und Untersuchung von Lagerstätten nutzbarer Mineralien*, 1866, p. 86. C. H. Müller, *Freiberg's Berg. und Hüttenwesen*, Freiberg, 1883.

gneiss is a compound of orthoclase, quartz and dark-coloured mica with a distinctly foliated structure, readily separating it into parallel tables. Both the red and gray gneiss may be divided into a number of subordinate varieties, and sometimes include strata of other micaceous rocks. The lodes, of which about 900 are known to exist in the Freiberg district, have, in accordance with the nature of their several veinstones, been classified as follows :—

1. Noble Quartz, or Braünsdorf Formation.
2. Pyritic Lead Formation.
3. Noble Lead, or Brand Formation.
4. Barytic Lead, or Halsbrücke Formation.

B. v. Cotta regards this as being also very nearly the order of their respective ages, for, although there is little doubt that the veins first mentioned are the oldest, the difference in age between 1, 2, 3, would appear to be very slight, if not even somewhat variable. There can be no doubt, however, that the barytic formation is the most recent. In addition to the foregoing the so-called copper formation must not be omitted, although it can only be regarded as a modification of the pyritic lead formation in which copper ores happen locally to predominate.

1.—The lodes of the Noble Quartz Formation consist principally of white quartz or hornstone, containing numerous fragments of country rock, from which the quartz frequently radiates as from a centre. The ores usually occur in geodes only, although, more rarely, they are found disseminated throughout the veinstone. They consist of very rich argentiferous minerals such as native silver, argentite, pyrargyrite, argentiferous mispickel, tetrahedrite, miargyrite, stephanite and polybasite. Blende, galena and iron pyrites occur in very small quantities, as do also some other minerals, such as calc spar, brown spar, heavy spar and fluor spar, which crystallise in drusy cavities. In addition to the foregoing, the following minerals are mentioned by v. Cotta as occurring in lodes belonging to this formation, namely :—gypsum, strontianite, pearl spar, diallogite, cerussite, metaxite, hypochlorite, antimony ochre, valentinite, geocronite, boulangerite, zinckenite, stibnite, kermesite, heteromorphite, berthierite, bournonite, copper pyrites, millerite, pyrostilpnite, limonite, specular iron ore and alabandite.

Some of these lodes attain a width of seven feet, and the quartz, which forms the principal portion of the gangue, is always firmly united to the country rock. Near Bräunsdorf, where the lodes of this class are most characteristically developed, they have been found workable only in the *schwarzen Gebirge*, a black, bituminous schist; they are generally barren in the ordinary mica schists. In the vicinity of Höckendorf, on the contrary, they are not unfrequently very rich in the gray gneiss.

About 150 lodes belonging to this class are known to exist in the Freiberg district, among which the following may be cited as being the most characteristic. The Verlorene-Hoffnung and Segen-Gottes lodes of the Neue-Hoffnung-Gottes Mine near Bräunsdorf; the Peter and Neuglück of the Alte-Hoffnung-Gottes Mine at Kleinvoigtsberg; the Wolfgang lode of the Segen-Gottes Mine near Gersdorf; the harder branch of the Reinsberg-Glück at the Emanuel Mine at Reinsberg, the softer branch of that double lode belonging to the pyritic lead formation; the Helmrich vein of the Romanus Mine near Siebenlehn; and, finally, the Gottlieb Lode of the Gesegnete-Bergmanns-Hoffnung at Obergruna.

2.—The lodes of the Pyritic Lead Formation contain various metallic sulphides enclosed in a quartzose gangue; the principal metalliferous minerals being argentiferous galena, blende, iron and copper pyrites, and mispickel. In some cases ores of copper so preponderate as to give rise to what has been called the copper formation. Rich silver ores, calc spar, heavy spar, fluor spar, &c., occur in very subordinate quantities only, and are usually found in the form of crystals lining the interior of drusy cavities, where they are evidently a more recent formation. The following other minerals, many of them of secondary origin, have been found in lodes belonging to this class:—hornstone, opal, gypsum, cerussite, pyromorphite, malachite, azurite, tyrolite, pharmacosiderite, scorodite, pharmacolite, cobalt bloom, pitticite, copperas, nacrite, allophane, chlorite, chrysocolla, scheelite, atacamite, stilpnosiderite, lampadite, melaconite, limonite, cuprite, specular iron ore, traces of cassiterite in blende, native silver, native copper, redruthite, stromeyerite, bournonite, polybasite, argentite, freieslebenite, tetrahedrite, tennantite, erubescite, pyrargyrite and marcasite. The outcrops of such lodes are often much decomposed, and exhibit well-defined and abundant gossans. This formation is most extensively developed to the north-east of Freiberg, several lodes belonging to this class being worked in the Himmelfahrt Mine. Among the 300 lodes enumerated by v. Herder as belonging to this formation the following may be regarded as characteristic, namely, the Frisch-Glück, Gottlob, Abraham, and Jung-David lodes of the Himmelfahrt Mine; the Laura and Abendstern of the Neuer Morgenstern Mine; the Jung-Andreas of the Krönor Mine, and the Leander of the Alt-Mordgrube.

As already stated, the so-called copper lodes are merely a modification of the pyritic lead formation, containing, in association with quartz, various copper ores, such as copper pyrites, redruthite, erubescite, tetrahedrite, &c., and, as products of decomposition, malachite, azurite, cuprite, &c. The Gottlob, Franzer, and Heinrich lodes of the Morgenstern Mines are cited as examples of this modification.

3.—The predominating gangue of the lodes belonging to the Noble Lead Formation consists principally of various carbonates, especially brown spar and diallogite, associated with quartz. The most important ore is galena, which is somewhat richer in silver than is that of the preceding formation, and often forms the middle layer of symmetrically formed lodes which, in addition, contain blende and iron pyrites. These are, more frequently than in the pyritic lead formation, accompanied by rich silver ores such as pyrargyrite, argentite, native silver, stephanite, &c., and are associated with various minerals of less commercial importance. Among these may be mentioned hornstone, opal, fluor spar, gypsum, heavy spar, calc spar, pearl spar, spathic iron ore, cerussite, pyromorphite, nacrite, cerargyrite, limonite, arsenious oxide, specular iron ore, rutile, pitchblende, arsenic, polybasite, acanthite, freieslebenite, tetrahedrite, copper pyrites, mispickel and realgar.

Von Herder has enumerated about 340 veins as belonging to this formation, which are found chiefly in the neighbourhood of Brand and Erbisdorf. The Traugott, Carl, Ludwig, Hülfe-Gottes and Gottholder lodes of the Beschert-Glück Mine, and the Felix and David lodes of the Himmelsfürst, are characterised by the presence of diallogite and brown spar. On the other hand, the gangue of the following lodes is more largely composed of quartz or semi-opal with proportionately little brown spar, namely, the Segen-Gottes, Benjamin and Gesellschafts-Freude of the Einigkeit, and the Beschert-Glück of the Himmelsfürst Mine.

4.—Heavy spar forms the predominating and characteristic veinstone of the lodes of the Barytic Lead Formation, in which it is symmetrically arranged in parallel layers, between which occur thin bands of galena, blende, pyrites, quartz and fluor spar. The centre of the lode sometimes contains large drusy cavities in which occur the above-mentioned minerals associated with rich silver ores and various beautifully crystallised carbonates. In addition to the foregoing characteristic minerals the lodes belonging to this class contain the following, namely: agate, opal, gypsum, pseudomorphs after apatite, calc spar, pearl spar, brown spar, spathic iron ore, cerussite, pyromorphite, erythrine, nacrite, beryl, chloropal, cerargyrite, limonite, specular iron ore, pitchblende, native silver, arsenic, bismuth, clausthalite, bournonite, stephanite, polybasite, argentite, tetrahedrite, copper pryites, cobaltine, smaltine, copper-nickel, millerite, pyrostilpnite, pyrargyrite and realgar. Portions of these lodes are not unfrequently found to have become brecciated through the repeated opening of the vein fissure, and fragments of comby veinstone which have thus become detached, have been reunited in positions very different from those which they originally occupied. A concentric banded structure, resulting in cockade ores, is by no means unfrequent in these lodes, some of which are as much as seven feet in width. The Halsbrücke vein may be regarded as the finest example of a vein belonging to this formation. Von Herder enumerates about 130 veins as being of this class.

The lodes belonging to these different formations do not, however, always exhibit any distinct or characteristic peculiarities, and in some cases their classification becomes extremely difficult, since minerals of comparatively recent age are often found associated in the same veins with others belonging to a much earlier period. This may probably be explained either by a previous incomplete filling of the fissure, or by its having been repeatedly re-opened.

These lodes, which are distributed in nearly parallel zones, have been classified by v. Beust[1] into the four following groups, in accordance with the direction of their strike.

a. The first group consists of a number of lodes whose strike is from north-east to south-west, with a nearly perpendicular dip, so that the layers of gneiss, which are almost horizontal, are cut through nearly at right angles to their bedding. Their veinstone belongs partly to the Noble Lead Formation and partly to the Pyritic Lead and Copper Formation.

b. The strike of lodes belonging to the second group is nearly from north to south, and the dip is much less considerable than that of the lodes above described. They form two nearly parallel bands, the one south of Freiberg, between Striegis and the Three Crosses, and the other between the town of Freiberg and the River Mulde. The matrix of the more southerly group belongs principally to the Noble Lead Formation, while that of the other, on the contrary, belongs to the Pyritic Lead Formation. Both of these intersect group *a* at acute angles, and give rise to a local enrichment of the ores.

[1] v. Beust, *Berg. und Hüttenm. Zeitung*, 1881, p. 377.

c. A third principal strike is from south-east to north-west; the lodes coursing in this direction nearly all belong to the Pyritic Lead Formation, and are scattered over a considerable area between Langenau and Freiberg. On the south-west of Freiberg they dip, for the most part, towards the south-west, but on the north-east of that town their dip, although almost perpendicular, is towards the north-east. They intersect and frequently displace the groups *a* and *b*, such intersection being often characterised by an increase in the richness of the ores.

d. The fourth group, of which the strike is north-east and south-west, and the dip north-west, consists of lodes belonging to the Noble Quartz Formation, comprised within a band, fifteen miles in length and five in breadth, extending from Nossen and Oederan to the north-west of Freiberg. Although these lodes in their general direction resemble those of class *a*, they have a very different matrix, and their direction is somewhat more variable.

In addition to the foregoing predominating directions of strike, many of the lodes in the Freiberg district follow intermediate courses, and therefore cannot be classified under any of the preceding groups. Isolated veins frequently occur towards the limit of the mining field, especially in the neighbourhood of Frauenstein, Ammelsdorf, Höckendorf and Dippoldiswalde. Throughout the whole district the ground in the vicinity of the principal lode-junctions has been that most extensively worked. The whole of the lodes in the district around Freiberg, with perhaps the exception of those belonging to the Barytic Lead Formation, appear to be in some way in connection with the dykes of quartz-porphyry which traverse the gneiss of this region, and are usually intersected by the lodes. Boulders of this porphyry are found in the neighbouring upper *Rothliegendes*, while tuffs, apparently resulting from eruptions of the same rock, are found in the lower *Rothliegendes* of the same district; it is therefore probable that the Freiberg lodes belong, as a whole, to the period of the upper *Rothliegendes*.

The deepest sinking in the Freiberg district is at the Abraham shaft at the Himmelfahrt Mine, which was 297 fathoms deep in 1881, the average depth of the other shafts being about 165 fathoms. Not much sinking has been done in more recent years, most of the newer developments having been in a horizontal direction.

In the year 1881 the Freiberg district produced 27,594 tonnes of ore, worth £211,221.[1] The Himmelfahrt, the most important of

[1] *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen*, 1883, p. 19.

the Freiberg mines, yielded 13,235 tonnes of silver, lead, and copper ores, worth £66,110. The Himmelsfürst Mine at Brand produced 6,613 tonnes of ore, worth £61,164. The Vereinigt-Feld Mine at Brand produced 1,323 tonnes of ore, worth £8,496.

In 1894 the Himmelfahrt Mine, with which some smaller workings had been amalgamated, produced 12,847 tonnes of ore, worth £44,190, and the Himmelsfürst Mine 8,377 tonnes, worth £26,718. The Vereinigt-Feld Mine and four others are now amalgamated and known as the Mittelgrube; this produced 4,563 tonnes, worth £26,150. These three together with the Behilfe-Kurprinz Group, which produced 1,437 tonnes of argentiferous lead ores, worth £7,600, make up the State-owned mines of the Freiberg district, their total output being thus 27,757 tonnes, valued at £105,890 for 1894. The privately owned mines of this district only produced ores to one-third of the above value.[1]

Silver ore was discovered at Schneeberg[2] in 1410, but the mines were not worked until 1471, when, owing to rich discoveries having been made, miners flocked in great numbers from all sides in such a way that the new town on the Schneeberg, in the course of a few years, numbered 12,000 inhabitants. The richest mine was the St. George which, in 1477, yielded ore from which twenty tonnes of silver were obtained. The yield of the Schneeberg must, in the first thirty years, have been very large, and from the year 1471 to 1500 it is said to have yielded more than 160 tonnes of silver. In 1482, 166 mines were at work upon the Schneeberg, and the ore obtained was smelted at Zwickau. The yield of silver, however, rapidly decreased during the sixteenth century, and the production is now insignificant. On the other hand, the mining of cobalt ores, which were discovered in 1561, still continues to be of some importance.

The Schneeberg consists of large masses of granite surrounded by mica schists and clay slates. The lodes usually occur in the latter rocks, but are more rarely found in granite, their strike being so variable as to result in a perfect network of veins. According to their composition and relative ages H. Müller distinguished:—1. Copper ore veins. 2. Quartz veins destitute of ore. 3. Pyritic lead veins. 4. Barytic veins. 5. Cobalt veins. 6. Iron ore veins. (1.) The copper veins strike N. 15° to 60° E., dip to the north-west, and contain quartz with copper pyrites, erubescite, fahlerz, &c.,

[1] *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen*, 1895, p. 34.

[2] H. Müller, *Cotta's Gangstudien*, iii. p. 1. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, ii. p. 46. *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen*, 1883, p. 67.

and sometimes galena, blende, iron pyrites and arsenical pyrites. (2.) The quartz veins strike from N. 60° to 75° E., dip from 45° to 80° north-west, and very rarely contain ores. (3.) The pyritic lead veins strike from north-west to south-east, and dip to the south-west; they contain quartz, pyrites, blende and galena. (4.) The barytic veins yielded, in the fifteenth and sixteenth centuries, astonishing riches in silver ore. They strike from north to south, dip at a considerable angle, and contain heavy spar, fluor spar, calc spar, quartz, silver, lead, cobalt, nickel and bismuth ores. (5.) At Schneeberg the cobalt veins are now the most important. They are nearly 150 in number, and their direction is very various. These veins contain quartz and hornstone, with, more rarely, calcite and brown spar, also cobaltine, native bismuth, iron pyrites, galena, pyrargyrite, native silver, and various other minerals, some of which, particularly ores of uranium, are rare. (6.) The iron lodes sometimes attain a thickness of ninety feet, and are filled with hornstone, quartz, amethyst, compact hæmatite, and brown and yellow iron ores. The veins occur on the borders of the granite or porphyry and the crystalline slates. Similar lodes occur at Marienberg, Annaberg, Joachimsthal, Johanngeorgenstadt, and other localities in the Erzgebirge. A. v. Groddeck considers these lodes as typical examples of veins which contain cobalt and nickel ore, rich silver ores, various gangues, and numerous subordinate minerals.

The Schneeberg mines during the year 1881 produced in the aggregate 158 tonnes of nickel and cobalt ores, of the total value of £5,902, together with 1,315 tonnes of silver ore, and 59 tonnes of bismuth ore, worth £3,292 and £16,933 respectively. In 1894 their production was unimportant, being only 372 tonnes of cobalt and nickel ores, and 1 tonne of pitchblende, worth together about £32,000, from the Schneeberger-Kobaltfeld Mine, and 2 tonnes of bismuth ore, valued at £300, from a neighbouring working.

Mining was commenced at Marienberg[1] in 1521, on a plateau of gneiss lying between the Bockau, the Schletten, and the Zschopau rivulets. This gneiss is traversed by veins containing silver and tin ores, which vary in width from two to thirty inches, and which traverse one another in such a way as to form a complicated network. About 140 silver veins are known at Marienberg, of which the gangue consists of decomposed gneiss, clay, quartz,

[1] H. Müller, *Cotta's Gangstudien*, iii. p. 290. *Jahrbuch für das Berg und Hüttenwesen im Königreiche Sachsen*, 1883, p. 34.

fluor spar and heavy spar, which, in addition to various ores of silver, contain copper ores, galena, blende, and ores of cobalt and nickel. The tin veins, which were formerly worked chiefly in the Martersberg and Wildesberg, are essentially composed of quartz and clay in which oxide of tin is sparingly disseminated. At the end of the seventeeth century about twenty-five tonnes of tin were annually produced at Marienberg; in the middle of the last century the annual production was only 15 tonnes, from which time up to 1850, when operations were suspended, the production did not exceed 10 tonnes per annum. No tin was produced in 1881, but 111 tonnes of silver ore, worth £7,649, were obtained from the Vater-Abraham Mine at Marienberg. This same mine was the only one in operation in this district in 1894, in which year it produced 65 tonnes of silver ore, valued at £2,760.

Near Annaberg the gneiss of the Pöhlberg is frequently broken through by basalt, by which rock in some places it is also overlain. Several silver veins occur in this locality, and many of them have been extensively worked. The lodes, of which the strike is nearly east and west, are usually only a few inches in thickness, and have a gangue composed of quartz and fluor spar, with occasionally a little heavy spar. In these veins are found native silver, pyrargyrite and argentite, together with ores of cobalt, nickel and copper. Numerous remains of ancient tin-streams may still be traced in the wooded district south of Annaberg, but no ore has been raised in it for some time.

The Schwarzenberg district[1] consists chiefly of mica schists through which protrude various masses of granite which are generally surrounded by gneiss, and are frequently traversed by greenstones and by other eruptive rocks. The ore deposits of this region, now of comparatively small commercial importance, consist of bed-like veins associated with greenstones, and containing small quantities of many different ores, and of various lodes of hæmatite.

In the neighbourhood of Johanngeorgenstadt and Eibenstock there are numerous veins and branches, chiefly in the granite, containing iron ores with a little oxide of tin, while in the mica schist of the Fastenberg there are veins containing silver and cobalt. The strike of the tin lodes is very variable and their dip in every way irregular; their filling closely resembles granite, and

[1] Oppe, *Cotta's Gangstudien*, ii. p. 132. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 2nd ed. ii. p. 37. *Jahrbuch für das Berg und Hüttenwesen*, 1883, p. 67.

tin ore, when present, generally occurs either in pockets or in ribbons. In addition to ores of iron and tin these veins contain many subordinate minerals, including wolfram and molybdenite, with occasionally galena and native gold. In the vicinity of metalliferous greenstones the veins of this district contain ores of silver, cobalt and bismuth.

The lodes producing iron ores sometimes occur singly, but are at others associated in groups, one of the most important of which intersects the mass of granite a little east of the town of Eibenstock. They also frequently occur as contact deposits between granite and mica schist, and are more numerous in the granite than in the latter rock, which they, however, sometimes follow along its line of strike. As subordinate minerals these veins contain various ores of copper and bismuth, and in 1834 seams of anthracite, sometimes as much as five inches in thickness, were found extending for a distance of nearly forty feet in a lode of hæmatite at the Lorenz Mine, at Rehhübel. The lode at this point consisted principally of fragments of granite, schist, quartz, hornstone, &c., embedded in clay, and the anthracite appears to have been derived from the adjoining mica schist which, locally, contains seams of coaly matter, fragments of which had fallen into the vein-fissure, together with pieces of the country rocks. The texture of these lodes is irregular and granular, and they seldom show any indication of a comby structure; the wall rock is often strongly impregnated with iron for a great breadth on either side of the vein.

In the year 1881 the Johanngeorgenstadt mines produced $2\frac{3}{4}$ tonnes of bismuth ore, worth £1,933, this being the sum of the production of five different mines. In 1894 the total production was only 2,817 tonnes of ore, chiefly of bismuth and cobalt, valued at £2,973; one mine, the Stamm-Assen-Fundgrube produced 1,767 tonnes of these ores.

The tin-producing district of Altenberg and Zinnwald[1] is situated in the Saxon Erzgebirge, between Freiberg and Teplitz.

Tin was discovered at Altenberg in 1458, and for a number of years from 250 to 300 tonnes of metallic tin were produced annually. The production from 1516 to 1523 was, on an average, 175 tonnes of tin per annum. This decreased about the middle of the sixteenth century to only 100 tonnes. The Altenberg tin stockwork (*see* page 170) is a peculiar mass of granite continuing to an unknown depth, surrounded by quartz-porphyry, granitic porphyry, and granite. The technically important part of the deposit is the

[1] H. Müller, *Berg. und Hüttenm. Zeit.* 1865, p. 178; E. Reyer, *Zinn*, 1881, p. 6.

Zwitter or *stockwork-porphyry*, which is a dark-coloured rock consisting of quartz, mica, and finely divided tinstone ; in addition to these, arsenical pyrites, copper pyrites, iron pyrites, iron glance, wolfram, native bismuth, fluor spar and other rarer minerals are found in veins. As there is neither a felsitic ground-mass, nor are any large crystals separated out, the name *Stockwerks-porphyr* used by the miners is petrographically unsuitable, and the name *Zwitter* is to be preferred. This rock is said to yield from ½ to ⅓ per cent. of tin ore, and is traversed in all directions by quartz veins, which contain, in addition to the minerals of the *Zwitter*, molybdenite, bismuth glance, &c. They also contain red clays, quartz, and a little tin ore. The wall rock, whether consisting of granite, syenite, porphyry, or other material, is always stanniferous. These veins, often reaching a thickness of four inches, dip at a great angle, and form groups which traverse the stockwork and reach the adjacent porphyries and granites, where they are worked as isolated lodes.

The production of the Altenberg and Zinnwald districts in 1880 amounted in value to £17,000. This included tin ore to the value of £9,105 from two mines at Altenberg, and tin ore worth £53 from a mine at Zinnwald; the remainder principally consisted of iron ores. In 1894 the production was 1,013 tonnes of iron ores, worth £354, 211 tonnes of dressed tin ore, worth £4,739, and 39 tonnes of wolfram, worth £1,149. The Vereinigt-Feld Mine at Altenberg and Vereinigt-Zwitterfeld-Fundgrube at Zinnwald were the principal producers.

Geyer and Ehrenfriedersdorf in Saxony, with Platten in Bohemia, constitute the second tin district of central Europe. Tin ores here occur not only in granite, but also in fissures in the adjacent slates. The stockwork of Geyer resembles that of Altenberg, being an irregular conical mass of granite with an ellipsoidal base, enclosed in gneiss and mica schists. In the granite there are innumerable veins, varying from ½ inch to 4 inches in thickness, which form nineteen distinct groups striking N. 45° to 60° E. and dipping from 70° to 80° towards the north-west. They continue into the adjacent gneiss and mica schists, with the same strike and dip. The veins contain principally quartz, with tinstone, arsenical pyrites, beryl, topaz, apatite and fluor spar. Manès[1] has calculated that the Geyer mines produced, during the period from 1400 to 1778, 6,730 tonnes of metallic tin. No tin ore was raised at Geyer in 1880. Ehrenfriedersdorf produced, during the

[1] Manès, *Ann. des Mines*, 1824, p. 288.

period from 1490 to 1497, from 60 to 90 tonnes of tin per annum, and, from 1507 to 1520, 50 to 60 tonnes were annually produced. In 1695, 68 tonnes were produced, and at the beginning of the last century from 180 to 200 tonnes of tin were annually raised; in 1770 the yield was only 60 tonnes. At the end of the eighteenth century the production decreased to 25 tonnes, and continued between 10 and 20 tonnes until the mine was closed in 1870.

The production of iron ores in the Erzgebirge is very small.[1] During the year 1881, the Neue Silberhoffnung Mine at Schwarzenberg produced 1,380 tonnes of iron ore, worth £835, and the Rother Adler 3,608 tonnes of iron ore, worth £2,128. In the Fichtelgebirge, between Stenn, near Zwickau, and Christgrün, iron ores occur in association with diabase and siliceous slates. In 1881 the Frischglück Mine at Stenn yielded 599 tonnes of iron ore, worth £239, the other mines in the district producing nothing. In 1894 the total production of iron ores was but 1,043 tonnes.

The value of the total production in Saxony of ores of every description during the year 1881 amounted to £273,691.

In 1894[2] the total production of the metalliferous mines of Saxony was 39,030 tonnes, valued at £186,160; the main items were as follows:—

	Tonnes.	£
Silver ores (including argentiferous lead, etc., ore)	14,628	99,950
Arsenical, iron, and copper pyrites	13,045	6,698
Galena	3,412	35,148
Bismuth, nickel, and cobalt ore	2,980	35,102
Wolfram	39	1,149
Tin ores	211	4,739

The principal metals reduced from the above ores at the Freiberg smelting works were:—

Silver	31,636	kilogr.
Lead	4,619	tonnes.
Copper	21	,,
Zinc	135	,,
Tin	51	,,

The ore-production of Saxony has, however, been in a retro-

[1] *Jahrbuch für das Berg. und Hüttenwesen im Königreiche Sachsen*, 1883, p. 44. *Ibid.* 1895, p. 73.

[2] *Ibid.*, pp. 72,

grade condition for a good many years, as is shown by the following table[1] of total outputs of ore since 1890:—

Year.	Tonnes.	£
1890	45,638	281,000
1891	51,633	280,400
1892	48,538	254,800
1893	40,376	218,500
1894	39,030	186,100

SILESIA[2].—About the beginning of the twelfth century, gold mining was commenced with great success at Goldberg, while copper mining at Kupferberg and Rudolstadt, and iron mining near Schmiedeberg were begun at nearly the same time. Agricola mentions the mines of Reichenstein and Altenberg, where a gray pyrites was smelted for gold and silver. In Upper Silesia the oldest mining was for lead ores at Scharley, Dombrowka, and Beuthen; it was commenced in the twelfth century, but was abandoned in 1363 on account of the increasing quantities of water. Mining was resumed in 1526 at Tarnowitz, where it was still flourishing in 1552, and in spite of the plague of that year, the mines of the district yielded no less than 5,000 marks of fine silver and 650 tonnes of lead. This industry was finally stopped by the Thirty Years' War, and was only partially resumed in 1784. In 1860 lead mining was re-commenced at Beuthen, and in 1881 Upper Silesia produced no less than 21,084 tonnes of argentiferous lead ores, representing a value of £154,617.[3] In 1894[4] the output was 32,508 tonnes, valued at £114,500, being an increase of nearly 50 per cent. in quantity and a decrease to nearly the same extent in value, owing to the fall in the prices of the two essential constituents of the ores since the former date.

Calamine mining at Beuthen, on which the present important zinc industry of Silesia is chiefly founded, is of much more recent date. In 1560, calamine was mined, roasted, and sent to Holstein and Sweden for the direct manufacture of brass. This industry first became important about the close of the eighteenth century, and in 1792 there were produced 900 tonnes of calamine. Upper Silesia yielded in 1881, from fifty mines, 553,487 tonnes of zinc ore, representing a value of £357,307, and gave employment to 9,587 workmen.[5] By 1894 the volume of the industry had undergone

[1] *Jahrbuch für das Berg. und Hüttenwesen im Königreiche Sachsen*, 1895, p. 89.

[2] v. Carnall, *Zeitschr. f. Berg. Hütt. u. Salinenw.*, 1853, p. 3. Pietsch, *ibid.* xxi. 1873, p. 292.

[3] *Ibid.* xxx. 1882, p. 182.

[4] *Ibid.* xliii. 1895, p. 151.

[5] *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxx. 1882, p. 176.

no very marked change: 9,726 men were employed in the mines and the output for the year was 589,240 tonnes (55 per cent. calamine and 45 per cent. blende) valued at £254,790. For the last twenty years the output seems to have been fairly steady at between 500,000 and 600,000 tonnes per annum, representing about 80 per cent. of the total zinc ore production of Germany. Here, as in other zinc mining districts, the proportion of blende is gradually increasing whilst that of calamine is proportionately diminishing. The quantity of metallic zinc produced in Silesia in 1894 was 92,544 tonnes.[1]

The elevated plateau of Upper Silesia bordering, towards the east, on Russian Poland, is covered, superficially, by deposits of alluvium, beneath which various older formations occur in the following order, and usually without interruption :—

1. Tertiary.
2. Cretaceous.
3. Jurassic.
4. Triassic ......
   - Keuper Sandstone with beds of clay ironstone.
   - *Muschelkalk*, accompanied by deposits of zinc, lead, and iron ores.
   - Bunter Sandstone.
5. Carboniferous rocks containing beds of sphærosiderite.

These formations extend into Poland.

The most important metalliferous ores of Upper Silesia are calamine, galena, and iron ores in the *Muschelkalk*, ironstones in the Keuper, and sphærosiderite in the Carboniferous formation.

In Upper Silesia, and in Poland, the deposits containing zinc and lead ores are enclosed in beds of crystalline dolomite of the lower *Muschelkalk*, sometimes called the ore-bearing dolomites. Brown iron ore forms irregular beds and nests in the limestones and dolomites of the lower *Muschelkalk*, and with it are found ores of zinc. The most important zinc ore deposits occur in dolomites which have been deposited in troughs in the *Sohlenkalkstein* or floor-limestone (also spoken of by the miners as the *blue floor*), of the lower *Muschelkalk*, and extend from Tarnowitz in an east-south-east direction through Beuthen into Poland. The upper Silesian zinc ores consist partly of carbonate and silicate of zinc, with compact blende, but principally of zinciferous brown ironstone, zinciferous dolomite containing iron, "red calamine," and of zinciferous clays and floor-limestone known as "white calamine,"

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.* xliii. 1895, p. 139.

this "white calamine" appearing to be an ore formed by metasomatic replacement of portions of the floor-limestone.[1] In these deposits the white calamine usually forms the lower bed, and red calamine the upper. Galena occurs, sometimes in the form of grains in the dolomite, sometimes as strings or perhaps as gash veins in the dolomite, and at others as seam-like deposits either at the junction of the floor-limestone and dolomite or immediately above. The thickness of this bed is not usually more than 1½ inches, but in places it increases to 2 feet 4 inches. It is somewhat difficult to account for the origin of the zinc in these deposits, but Runge[2] is inclined to believe that the calamine is the result of the solution and concentration of finely divided zinc ores originally disseminated in the dolomite. The fact that the masses of calamine change into compact blende as the depth increases also suggests that the ore originally deposited was blende, which has subsequently become converted into calamine. The latter opinion seems to be now generally received.

The crystalline ore-bearing dolomite occupies a series of basins in the synclinal folds of the floor-limestone, the anticlines of which separate the different mineral districts; this dolomite has been exposed to extensive weathering, leaving residual deposits of brown hæmatite, into which some of the smaller dolomite basins have been completely converted. This seems to be an intelligible explanation of the genesis of the iron ores, which has been pretty generally accepted.

At the calamine mine of Cäcile in Upper Silesia the transition of compact blende into calamine has been repeatedly observed. This mine, to a depth of 25 fathoms, had yielded calamine only, while 6 fathoms deeper the ore was found to have an altered character, consisting, to a thickness of from 6 to 9 feet, of calamine, which was traversed by numerous strings of blende, and contained large masses of this mineral which often enclosed fragments of galena. Many specimens of ore exhibited a kernel of blende with an external covering of calamine. In 1881 this mine produced 36,789 tonnes of calamine, 8,454 tonnes of blende, and 2,369 tonnes of lead ore. As the workings extended in depth the calamine was more and more replaced by blende until in 1894 the output was:—

Calamine	5,467	tonnes.
Blende	41,692	,,
Galena	2,675	,,

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxxii. 1884, p. 333.

[2] Runge and Römer, *Geologie von Oberschlesien*, 1870, p. 545.

In the Samuelsglück Mines at Gross-Dombrowka, in the Neue Helene Mines at Scharley, and the Marie at Miechowitz, deposits of blende, 9 feet in thickness, have been discovered.

At the Friedrich Mine at Tarnowitz the galena deposits consist of many irregular bunches of ore, and the Tarnowitz miner also distinguishes a hard- and a soft-ore bed. The hard-ore bed is formed either of compact galena, usually under an inch in thickness, but sometimes swelling out to above 2 feet, or of hard dolomite containing fissures filled with compact galena. Where the soft-ore bed, which varies in thickness from 10 inches to 2 feet, occurs, the dolomite is divided into separate rounded blocks, between which is found a yellowish or brownish iron ochre, which contains galena in irregular lumps, plates, or crystals; in such cases the dolomite itself loses its light colour and becomes brown. A bed of brown iron ore is frequently found above the soft-ore bed. The brown colour of the dolomite, and the formation of the fissures occurring in it, are, without doubt, both due to the same cause, namely, the partial solution and alteration of the rock, the iron ochre and the brown iron ore being residua from this process of decomposition. The soft-ore bed sometimes appears in another form, namely, as an ochreous or bituminous clay with enclosures of galena, as in the Trockenberg and some other districts. The galena is often accompanied by cerussite, anglesite, tarnowitzite, and heavy spar, the latter mineral having been found only in a trial shaft at Stolarzowitz in beds of from $2\frac{3}{4}$ to 4 inches in thickness above the floor-limestone. This heavy spar contained galena, and was in places much disintegrated and decomposed. At the Friedrich Mine a second lead ore bed is known, ten to fifteen fathoms above that described; it is, however, much more irregularly developed. After a long and steady career of several centuries this mine was closed down in 1754; after a lapse of thirty years work was recommenced and continued regularly. By the end of a century of work, in 1884, it had produced 114,000 tonnes of lead ore valued at at £1,050,000.

The zinc production of Upper Silesia has developed very rapidly; the first year for which authentic records are available is 1811, in which year 604 tonnes of ore were produced. The next sixty years showed an output of about eleven million tonnes; that for 1881 and 1894 has already been given on pages 421 and 422. In 1881 there were 40 mines at work, whilst in 1894 this number had been reduced to 29; the output of individual mines was, however, greater at the latter date, as is seen from the following statements of the productions of the more important mines in each of the above years :—

1881.[1]

Name.	Calamine.	Blende.	Lead Ore.
	Tonnes.	Tonnes.	Tonnes.
Neue Helene (at Beuthen)	116,754	24,724	5,287
Scharley	55,640	—	293
Bleischarley	31,857	16,861	1,927
Samuelsglück	12,617	33,736	968
Cäcile	36,789	8,454	2,639
Marie	18,789	5,781	2,239
Elizabeth	19,491	—	48

1894.[2]

Name.	Calamine.	Blende.	Lead Ore.
	Tonnes.	Tonnes.	Tonnes.
Neue Helene	82,202	65,523	12,625
Bleischarley	79,770	41,781	4,438
Samuelsglück	49,068	33,241	507
Scharley	39,561	—	—
Wilhelmsglück	33,985	—	1,800
Cäcile	5,467	41,692	2,675
Neuhof	2,595	19,732	848
Cons. Maria	1,903	12,123	1,391
Jenny Otto	10	27,854	3,036
Cons. Neue Victoria	—	6,890	293

The total mineral[3] production of Silesia in the two above years is shown in the following comparative table :—

Mineral.	1881.		1894.	
	Quantity.	Value.	Quantity.	Value.
	Tonnes.	£	Tonnes.	£
Calamine	453,687	307,307 (Calamine and Blende)	323,302	254,798 (Calamine and Blende)
Blende	90,800		265,938	
Lead ore	21,084	154,617	32,508	114,551
Copper ore	7,584	2,654	25	171
Iron ores	764,479	132,644	615,013	170,195
Nickel ores	—	—	1,341	2,682
Arsenic ores	—	—	2,222	4,444
Pyrites	—	—	3,528	1,265

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxx. 1882, p. 176.
[2] *Ibid.* xliii. 1895, p. 140.
[3] *Ibid.* xliii. 1895, p. 18.

In 1881, a single mine, Stilles-Glück at Jauer, was producing copper, but, as appears from the table, the production of ores of this metal had all but come to a close in 1894.

It may be added that cadmium is chiefly extracted from Silesian zinc ores, the production of the province being four or five tonnes annually.

With respect to the production of iron ores in Silesia, that is to say, in the mineral district with which that province coincides, namely *Oberbergamtsbezirk* Breslau,[1] the distribution of the various kinds raised in the respective years was as follows:—

Description.	1881.		1894.	
	Quantity.	Value.	Quantity.	Value.
	Tonnes.	£	Tonnes.	£
Clay and brown iron ores of Tertiary, Jurassic, and Keuper ages	2,361	640	5,816	1,346
Brown iron ores of the *Muschelkalk*	746,612	127,012	573,994	148,506
Clay ironstone and sphærosiderite of the Coal-measures	15,031	4,945	7,246	2,452
Bog iron ores	475	47	—	—
Magnetic iron ores	—	—	27,957	17,890
Totals	764,479	132,644	615,013	170,194

Alsace-Lorraine.—This German State produces no metalliferous minerals with the exception of iron ores; the whole of these are derived from the bedded deposits of minette to which reference has already been made. The industry is of comparatively recent growth, but has already attained very considerable dimensions; in 1883 the output was 1,644,321 tonnes, in 1890 it was 3,256,270 tonnes, and in 1893 it was 3,607,233 tonnes, and in 1895 [2] it reached 4,222,352 tonnes, valued at £421,000.

Luxembourg.—Very similar conditions obtain in this State, which is included in the German Customs Union, and which has important deposits of iron ore, whose production is generally included with that of Germany. The ores occur in beds which are a continuation of the beds of minette of Alsace-Lorraine and of France, which have previously been described (*see* pages

[1] *Zeitschr. f. Berg. Hütt. u. Salinenw.* xliii. 1895, p. 129.
[2] Officially communicated.

327 and 353). They are chiefly worked in the neighbourhood of Esch, where four beds are known. The upper one, close to the surface, is only worked in places, as it is often too siliceous to be worth exploiting. At varying distances below the first is a bed of red ore about 7 feet thick; 35 to 40 feet below this, is another bed 8 feet to 16 feet thick, of a dark gray colour, and finally 23 feet below this, a bed of brown ore about 9 feet thick. Their position is practically horizontal or dipping at very low angles. The red bed is the best, the ore averaging 38 to 39 per cent. of iron, whilst the gray and brown ores average 36 to 38 per cent. The beds are found to diminish both in number and thickness as they extend southwards.[1] The annual production of iron ores in Luxembourg is shown in the following table:—

1883	2,575,976	tonnes.
1890	3,359,413	,,
1893	3,351,938	,,

The remaining German States are of little or no importance as producers of metalliferous minerals, Bavaria, Hessen, and Brunswick producing a little iron ore, but practically nothing else.

For example, the output of metalliferous minerals in the extensive kingdom of Bavaria was as follows during the year 1895,[2] when it did not differ greatly from the preceding years, although a small quantity of copper ore (650 tonnes) was raised in 1893:—

Description.	Weight.	Value.
	Tonnes.	£
Iron ores	147,159	31,320
Manganese ores .	150	22
Pyrites	1,955	2,923
Total value		34,265

Their relative insignificance may also be seen by comparing the tables about to be given of the mineral production of Prussia, and that already given of Saxony, with the output of the entire German Empire.

[1] *Oesterr. Zeitsch.* 1892, p. 601.

[2] *Uebersicht der Produktion des Bergwerks—Betriebes im bayerischen Staate für das Jahr* 1895, pp. 3, 4.

Production of Metalliferous Minerals in Prussia during the Year 1894.[1]

Description of Ore.	Quantities.	Values.
	Tonnes.	£
Iron ore	4,012,446	1,228,244
Zinc ore	727,645	513,410
Lead ore	144,724	580,018
Copper ore	579,132	802,516
Silver and Gold ores. . .	6	1,856
Mercury ore	—	—
Cobalt ore	203	1,148
Nickel ore . .	1,341	2,682
Arsenic ore . . .	2,222	4,444
Manganese ore	42,526	19,790
Iron pyrites	123,149	43,119
Other vitriol ores	126	37
Totals	5,635,520	3,197,264

The relative importance of the various districts of Prussia is well shown by the following table of the output of metalliferous minerals in each *Oberbergamtsbezirk* for the year 1895, compiled from information kindly supplied by the various *Oberbergamtsbezirke* :—

	Breslau.		Bonn.		Halle.		Clausthal.		Dortmund.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.		Quantity.	
	Tonnes	£	Tonnes	£	Tonnes	£	Tonnes		Tonnes	
Iron ores	482,863	132,117	2,420,188	838,511	46,955	9,997	400,721		334,365	
Zinc ores	579,977	281,099	97,049	188,366	—	—	13,361		15,792	
Lead ores	30,756	107,898	77,253	359,798	—	—	45,706		1,175	
Copper ores . . .	—	—	44,406	6,520	565,830	741,029	23,107		—	
Nickel ores . . .	2,051	820	6	16	1	1	101		—	
Arsenic ores . . .	3,046	6,092	—	—	—	—	—		—	
Pyrites	2,986	1,303	107,405	36,428	—	—	4,062		976	
Cobalt ores . . .	—	—	19	252	—	—	—		—	
Antimony ores . .	—	—	24	44	—	—	—		—	
Manganese ores .	—	—	39,882	21,183	—	—	—		—	
Silver ores	—	—	—	—	—	—	12		—	

[1] *Zeitsch. f. Berg. Hütt. u. Salinenwesen*, xliii. 1895, p. 20.

General Summary of the Production of Metalliferous Minerals in the German Empire, inclusive of Luxembourg, during the Year 1881.[1]

Description of Ore.	Quantities.	Values.
	Tonnes.	£
Iron ore	7,573,771	1,804,277
Tin ore	164	11,515
Copper ore	523,696	716,495
Lead ore	164,770	962,017
Zinc ore	659,530	479,721
Iron pyrites	125,057	63,968
Silver and Gold ores	26,787	213,772
Manganese ore	13,642	23,534
Cobalt ore	191	13,005
Nickel ore	6	97
Antimony ore	77	835
Arsenic ore	867	2,271
Bismuth ore	67	12,285
Uranium ore	3	514
Wolfram	44	648
Vitriol ores	21,018	2,472
Total value of Metalliferous Minerals produced in 1881		4,307,426

General Summary for 1893.[2]

Description of Ore.	Quantities.	Values.
	Tonnes.	£
Iron ore	11,457,533	1,990,053
Zinc ore	787,910	714,542
Lead ore	168,413	707,208
Copper ore	584,950	906,158
Silver and Gold ores	18,778	154,923
Tin ore	53	4,382
Cobalt, Nickel and Bismuth ores	4,490	37,742
Arsenic ore	2,758	5,078
Manganese ore	40,797	24,597
Uranium and Wolfram ores	43	2,155
Iron pyrites	121,329	43,737
Other vitriol ores	791	249
Total value of Metalliferous Minerals produced in 1893		4,590,824

[1] From the *Monatshefte für die Statistik des Deutschen Reichs*, x. 1882, p. 1.

[2] From the *Vierteljahrsheften zur Statistik des Deutschen Reichs*, *Berg. u. Hütt. Kalendar*, *Essen*. 1896, p. 180.

THE AUSTRO-HUNGARIAN MONARCHY.

Austria.

The Austrian Empire is rich in minerals of commercial value, and with respect to their great variety is not surpassed by any country in Europe. Gold, in notable quantities, is found in Hungary and Transylvania, silver occurs in the same countries and in Bohemia, while quicksilver, which is almost exclusively confined to Idria in Carniola, occurs also in small quantities in Hungary as one of the constituents of a mercurial tetrahedrite. Przibram in Bohemia and Villach in Carinthia produce lead ores; copper ore is found chiefly in Salzburg, and iron ores are mined in Western Galicia, Carinthia, Carniola, the Tyrol and Styria. Tin ore is obtained only at one or two places in Bohemia.

Bohemia.—Both gold mining and iron mining were extensively carried on in Bohemia previous to the Roman period, one of the most important of the ancient gold mines having been situated at Eule, about ten English miles south of Prague. This mine, which is known to have been in operation in 734, is said to have yielded in one year one and a half million ducats of gold, and in 1145 produced twenty-four cwts. of this metal. Silver mining began on the Birkenberg near Przibram, in Central Bohemia, in 843, where the workings are at the present time among the deepest in the world. At Mies, near Pilsen, silver and lead were mined previous to the year 1100, and in 1131 the town itself was founded. The mines were abandoned during the Thirty Years' War, but were resumed in 1696, and continue in operation to the present time. The silver mines at Iglau, Nellizau, and Eylau, were first opened in 1160. In consequence of the religious wars during the fifteenth and sixteenth centuries, mining was, to a large extent, abandoned, and many miners removed to the Erzgebirge, where, at Graupen, Geyer, Altenberg, Zinnwald, &c., tin ores had been discovered. Mining for lead and silver at Joachimsthal flourished at the beginning of the sixteenth century, and, in 1516, 8,000 miners were employed there. In the year 1518 a mint was erected in which the first *Joachimsthaler*, afterwards called *thaler*, whence the word *dollar*, was struck. The production of the Joachimsthal mines from 1516 to 1534 was more than 2,333,000 thalers, but here, as in the district generally, mining was for a time abandoned on account of the Thirty Years' War. Many of the mines were re-opened in 1700, and have continued in operation, with more or less success, to the present time. A copper mine, which in 1616 employed 2,000 miners, was formerly worked at Grasslitz, but was abandoned at the end of the eighteenth century and has not since been re-opened.

The town of Przibram[1] is situated thirty-one English miles south-east of Prague, upon a plateau varying from 1,650 to 1,950 feet above the Adriatic, and traversed by various chains of hills of comparatively inconsiderable elevation. There are no documents to show when mining operations first commenced at Przibram, but according to records preserved in the municipal archives a concession to re-open the mines was granted in 1527, since which period they have been continuously worked with varying degrees of activity and success.

The metalliferous deposits of this district occur in the form of veins enclosed in the lower beds of the Silurian formation of Bohemia, *l'étage* A of Barrande. The rocks are, for the most part, sandstones, quartzites, conglomerates, and schists, bounded on the east and west by granite and by a narrow band of clay slates belonging to *l'étage* A. The schists of *l'étage* B rest conformably upon the older slates, and above them come the sandstones of the grauwacke, which in their turn are covered by grauwacke slates of a mean thickness of about 3,250 feet. Above the grauwacke lie the sandstone and quartzite forming the extreme limit of the metalliferous group. All these beds have a strike of north 60° to 75° east; and between the sandstone and the slates of *l'étage* B, to the west of Przibram and Birkenberg, there is a fault, containing clay, a few inches only in width, the *lettenkluft*, which causes an extensive displacement of the strata; its direction, which is very constant, is N. 56° E., and its dip 79° north.

Recent investigations have caused geologists to modify considerably the system proposed by Barrande. According to Posepny[2] the divisions of Barrande correspond with the following geological periods:—

Étage A of Barrande . .	Archaic (gneiss, &c.). Precambrian.

[1] *Notice sur quelques-unes des Principales Mines de L'État Autrichien*, Paris, 1878, p. 5. "Bericht über die Thätigkeit des k. k. Ackerbau Ministeriums," *Oesterr. Zeitschr.* xxix. 1881, p. 553.

[2] F. Pošepny, "Beiträge z. Kentniss d. Montangeologischen Verhältnisse v. Příbram," *Archiv. f. Prakt. Geologie*, 1895, p. 619.

Étage B of Barrande . .		Cambrian.
„ C „ . .		
„ d „ . .		
„ D „ . .		Silurian.
„ E „ . .		
„ F „ . .		Devonian.
„ G „ . .		
„ H „ . .		

All of these appear to be conformable; in some parts of Bohemia, small patches of carboniferous age overlie the older rocks quite unconformably.

The Lower Silurian rocks are traversed by dykes of diorite, and by numerous metalliferous veins which are capped with gossan and, at depths below fifty fathoms, consist to a considerable extent of argentiferous galena. The thickness of the veins varies from 1 inch to 19½ feet, and nearly the whole of those which are extensively worked, appear in the grauwacke; several of them thin out and become impoverished on reaching grauwackes of greater tenacity near the surface, others, on the contrary, become richer in the vicinity of their outcrops, or where a change in the country rock takes place. Some of the veins cross the fault above referred to, and have been recognised in the schists at a great distance on the other side. The general strike of the more important of these very numerous veins is north and south, and very many follow closely the eruptive diorite dykes, as shown in the accompanying section (Fig. 92); some, however, are fissures in the stratified rocks, and on the other hand some fissures in the diorites are barren. Upon the whole, however, the mode of occurrence of these mineral veins appears to be closely bound up with that of the eruptive dykes.

In addition to galena, the veins contain blende, which is poor in silver, spathic iron ore, calcite, pyrargyrite and tetrahedrite, while argentite and native silver are but rarely found. The galena occurs in veins, branches and lenticular masses, or is disseminated through the compact quartzose gangue. Many of the veins have been explored for great distances, both on their strike and on their dip, without showing any decrease in richness, or variation in the gangue; in fact, as a general rule, the width of the veins and the proportion of silver in the galena increase with the depth attained. The longitudinal extension of the Przibram mining area is 4,550 fathoms, the breadth 2,380 fathoms, and the greatest depth yet attained over 600 fathoms. In this concession nineteen shafts are at work, of which the two deepest are the Adalbert with a depth

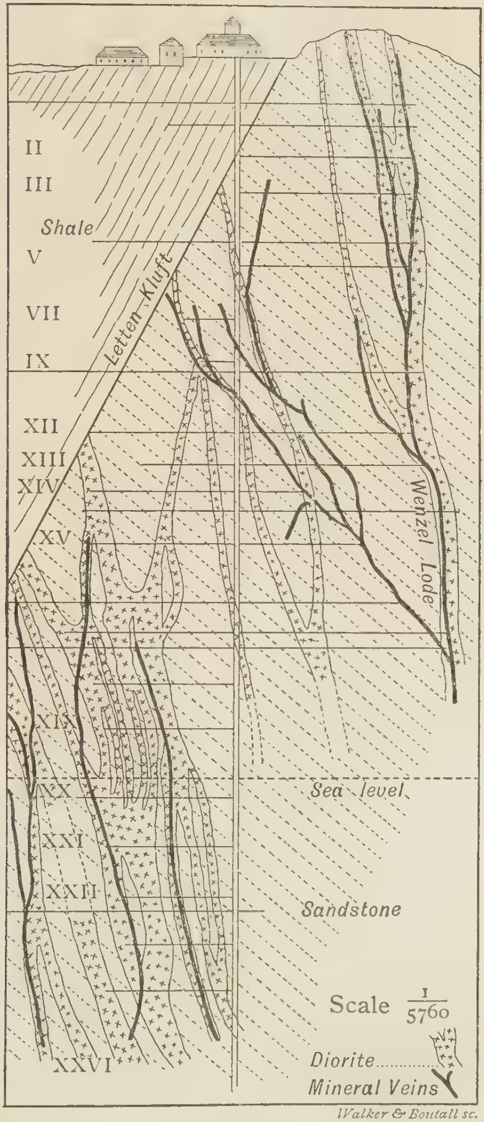


FIG. 92.—Section through the Anna Shaft at Przibram from West to East; after Pošepny.

of 1,099 metres (3,606 feet), and the Maria shaft with a depth of

1,070 metres (3,511 feet) in 1895.[1] It may be added that the former shaft, until recently the deepest in any metal mine in the world, extends down to 1,942 feet below sea level. A great fire, that broke out in the latter shaft in May, 1892, when it had reached the depth of 1,110 metres, has hindered its progress seriously. The underground workings communicate with the great drainage tunnel "Joseph II.," which is 13½ miles in length and 1,360 feet above the sea level; the total length of the galleries in these mines exceeds 152 miles.

The production of ores at Przibram is shown in the following table:—

Year.	Weight of dressed ore.	Containing	
		Silver.	Lead.
	Tonnes.	Kilogr.	Tonnes.
1876	8,062	23,202	3,792
1881	11,953	32,024	5,022
1886	13,532	35,656	5,284
1891	14,501	36,211	4,328
1894	18,334	38,824	5,179

The value of the ore produced in the last-named year was £299,800, and the number of men employed rather over 6,000, whilst there were but 5,450 in 1880.

The veinstone of the lodes which occur in the gneiss at Kuttenberg[2] is composed of quartz, felspar and calc spar. The mines were worked as early as 1237, and yield the following minerals, namely, iron pyrites, arsenical pyrites and blende, all containing silver, as well as argentiferous galena, copper pyrites, and various silver ores. Mining was resumed a few years since in order to supply the Przibram smelting-works with pyrites, which is required in the treatment of some of the poorer material. Through the Skalka shaft, which was only 23 fathoms deep in 1877, 102 in 1880, and as much as 138[3] in 1886, three productive lodes are worked. These veins, which are for the most part tolerably wide, are in places much pinched, but hitherto the productiveness of the mine has increased with its depth. In 1881, seventy-six men were

[1] F. Pošepny, "Beiträge z. Kentniss d. Montangeologischen Verhältnisse v. Pribram," *Archiv. g. Prakt. Geologie*, 1895, p. 619.

[2] *Oesterr. Zeitsch.* xxix. 1881, p. 555.

[3] *Oestr. Zeitsch.* 1888, p. 440.

employed, and 823 tonnes of pyrites, worth £1,234 were produced.[1] Since 1886 there has been no active mining, but prospecting operations have been continued; the mine, although producing no ore, had not been shut down in 1894.

The Frischglückzeche lead lodes at Mies[2] is the richest in that district, and there are but few which, in addition to lead ores proper, contain such a variety of other minerals. This lode, in common with all the others occurring in clay slate in the neighbourhood of Mies, has a general strike in the direction of 30° east of south and dips from 55° to 80° towards the west. In thickness it varies from a mere thread to eighteen feet and, with a quartzose gangue, contains galena, cerussite, pyromorphite, blende, iron pyrites and barytes. Drusy cavities of various sizes frequently occur in this vein, and the walls of these are often covered with crystals of quartz and galena, and with those of cerussite, barytes and blende; faultings of the lode are very rare.

In 1881 there were three mines working at Mies; these employed 510 workmen, and produced 2,370 tonnes of lead ore worth £19,564, and 322 tonnes of galena, with 0·65 per cent. of silver, worth £3,247; all these mines had been closed down before 1890.

The quaint little town of Joachimsthal[3] lies on the southern slope of the Bohemian Erzgebirge, in a ravine of which the direction is nearly north and south. Mining is believed to have commenced in this locality during the first years of the fifteenth century, and in 1517 the number of miners is stated to have been 8,000 and the town contained no less than 20,000 souls. A period of great productiveness ensued, in which the mines were in a most flourishing condition, silver ores being chiefly sought for. It would appear that between the years 1516 and 1589 about 9,800,000 ounces of silver were extracted from these mines. With the beginning of the seventeenth century, mining declined rapidly owing chiefly to the destructive wars of that period and to pestilence; even in 1750 very little mining was being done, the production of silver being only some 1,000 ounces yearly, but about this time a rapid improvement set in and a second era of prosperity commenced. The following table shows the decennial

[1] *Statistisches Jahrbuch des k. k. Ackerbau Ministeriums*, Vienna, 1882, p. 61.

[2] J. Schmuck, *Oesterr. Zeitschr.* xxx. 1882, p. 282. *Statistisches Jahrbuch des k. k. Ackerbau Ministeriums*, Vienna, 1882.

[3] *Principales Mines de l'État Autrichien*, Paris, 1878, p. 15. *Oest. Zeit.* 1881, p. 543.

production of silver at Joachimsthal between the years 1755 and 1824[1]:—

1755 — 1764	... ...	739,890 ounces.
1765 — 1774	... ...	243,270 „
1775 — 1784	... ...	369,180 „
1785 — 1794	... ...	412,560 „
1795 — 1804	... ...	326,970 „
1805 — 1814	... ...	127,530 „
1815 — 1824	... ...	138,870 „

Of recent years the output of silver has fallen off considerably.

The country rocks of the neighbourhood of Joachimsthal are for the most part mica schists enclosed between masses of granite. In the eastern portion of the mine, where there are some masses of included limestone, the lodes usually carry calcite as the predominating veinstone; but in the western part, where the veins are not unfrequently associated with dykes of porphyry, the gangue is almost entirely quartzose. There are seventeen veins striking north and south, and seventeen others of which the direction is east and west. It has been constantly observed that the former exhibit a tendency to become enriched where they pass through the porphyry or included limestone, while the latter set of veins are not similarly affected when they come in contact with these rocks. The ores raised contain silver, cobalt, nickel, bismuth and uranium. In the eastern division of the mine there are two shafts situated about 260 fathoms apart, the Einigkeit's shaft and the Kaiser Josef Shaft.

In 1864,[2] when the former shaft had reached a depth of 280 fathoms, a heavy outburst of water at a temperature of 25° C., and evolving sulphuretted hydrogen, took place and greatly interfered with underground operations. It took two years before this water could be successfully tubbed off and mining proceeded with.

The average annual production of ore of the eastern division during the period from 1877 to 1880 was 29⅓ tonnes of ore containing 4,497 oz. silver, 198 lbs. bismuth, 878 lbs. of uranic oxide, 1½ tonnes of arsenic, and 314 lbs. of cobalt and nickel, with a little lead, representing a total value of £1,687.

About this time it became evident that the uranium oxide was

[1] Babanek and Seifert, *Berg. u. Hüttenmännisches Jahrbuch*, xli. 1893, p. 94.
[2] *Ibid.* p. 136.

the most valuable product of these mines and workings were especially directed to develop the minerals yielding it. From 1881 to 1886 the average annual production was 38 tonnes of silver and uranium ores, worth about £6,520.

In the veins of the western division uranium ore was more especially sought for. These veins, of which the most important is the Geister Lode, are worked through two shafts, the Werner 235 fathoms deep, and the inclined Elias Shaft of 91 fathoms on the incline, or 72½ fathoms perpendicular depth. The average annual production of this division between the years 1881 and 1886 was 50 kilogr. silver, 65 kilogr. cobalt and nickel, 95 kilogr. bismuth, 950 kilogr. lead and 2,000 kilogr. of oxide of uranium, of a total value of £4,000.

The total production of Joachimsthal in 1894 was, silver ores 4·2 tonnes worth £198, and uranium ores 26·4 tonnes worth £5,940.

At Schlackenwald,[1] near Carlsbad, in North-western Bohemia, is found the continuation of the granitic outburst, in which is situated the tin district of the western Erzgebirge. But while the granites and slates in the latter district are much twisted and contorted, those of north-western Bohemia are nearly horizontal. The slates by which the granite was formerly covered have, for the most part, been removed by erosion, but in the Schlackenwald district, where the entire system has been pressed into the form of a deep trough, the slate still retains a considerable thickness. In the southern portion of this district, at Schönfeld, the granite adjacent to the slate consists entirely of a greisen exactly resembling the rocks of Zinnwald, and mining was here formerly carried on with considerable activity; but two small conical masses of granite north of Schönfeld and between that place and Schlackenwald, were even still richer. Of the smaller of these nothing is now known, since it has not been worked in modern times; the granite of the larger mass has, however, been continuously mined for many centuries, first by fire-setting, and afterwards by blasting. Enormous cavities were in this way formed until at last the rock crushed and the mine caved in; so that nothing is now to be seen of the granitic cone except a single pillar which was apparently found not worth working.

The production of tin at Schönfeld, near Schlackenwald, was in 1355 already considerable, and for a long time Schönfeld and

[1] E. Reyer, *Zinn.* 1881, p. 74.

Graupen were the only productive tin mines of central Europe. The working of the stanniferous rock here and at numerous other points attained a great importance in the sixteenth century. About this time, however, the production of Schönfeld fell off, and for more than half a century Schlackenwald was the most important tin mine in Europe. From the Schönfeld and Schlackenwald district 800 tonnes of tin were produced in 1550, and in 1580 Schlackenwald alone yielded from 300 to 400 tonnes. The rock at that time (1570-1660) yielded 0·5 per cent. of tin. According to Reyer, mining became of less importance after 1580, and he suggests, as the probable reason for this, that the price of tin, although it had in the course of the century nominally risen, had, in comparison with the price of food, &c., considerably fallen; secondly, the depth of the mines at the end of the sixteenth century had much increased, and, lastly, the percentage of ore appears, at least as regards Schlackenwald, to have decreased with the depth, as may be deduced from the following data:—

In the year	1570	the average percentage of	metal in the rock was	0·5
,,	1600	,,	,,	0·5
,,	1655	,,	,,	0·3 to 0·4
,,	1760	,,	,,	0·3 to 0·4
,,	1774	,,	,,	0·2 to 0·3
,,	1819	,,	,,	0·2
,,	1850	,,	,,	0·2 to 0·4

At the beginning of the seventeenth century Schlackenwald produced 170 tonnes, and Schönfeld 80 tonnes of tin per annum, but this was subsequently reduced to an annual production of 50 tonnes. Almost all the ore produced at Schlackenwald was obtained in the sixteenth century, during which period about 50,000 tonnes of tin were produced in this district, and as 300 tonnes of rock only yielded 1 tonne of tin, 15 million tonnes, or about seven million cubic yards, must have been worked to give the above yield. The whole of this rock, nearly as hard as quartz, must have been removed by fire-setting, and gad and hammer, and subsequently stamped and washed.

In Bohemia, and, in fact, in the whole of Austria, the production of tin in 1881 was confined to two mines, viz., the Maurizi Mine at Hengstererben, which produced 911 tonnes of tin-stuff worth £935, and the Graupen Mine which produced 140 tonnes of ore, worth £3,449. Since then the production has been steadily diminishing; since 1892 Graupen has been the only producing tin mine. Its output in 1893 was 26 tonnes and in 1894 only 24 tonnes of tin-ore (*Zwitter*) valued at £246. The total production of metallic minerals of Bohemia in 1881 [1] and 1894 [2] was respectively as follows:—

1881

	Tonnes.		Tonnes.
Gold ore	700	Bismuth ore	13
Silver ore	12,383	Antimony ore	187
Lead ore	2,377	Uranium ore	6
Zinc ore	10	Wolfram	62
Copper ore	20	Sulphur ore	3,011
Tin ore	1,051	Manganese ore	31
Iron ore	70,206		

1894

	Tonnes.		Tonnes.
Gold ore	1·9	Antimony ore	686
Silver ore	18,338	Arsenic ore	2·2
Iron ore	446,522	Uranium ore	26
Lead ore	1,661	Wolfram ore	40
Nickel and Cobalt ores	55	Sulphur ore	1,384
Zinc ore	1,080	Vitriol and alum shales	10,854
Tin ore	24	Manganese ore	9
Bismuth ore	570		

SALZBURG[3].—Mitterberg in the Salzburg Alps, where a bedded lode is worked in Silurian clay slates, is about five miles west of Bischofshofen. The deposit may be followed along its outcrop for a distance of nearly five miles, and it appears in several places to split up into two or more leaders. The present workings extend over a length of above 600 fathoms along its strike, and are situated partly upon the main lode and partly on one of its leading branches. The thickness of the lode, which is chiefly filled with *Lagerschiefer* [4] or sericite rock, averages from six to nine feet, and contains quartz, spathose iron ore, and copper and iron pyrites. The *Lagerschiefer*, which occurs only where there are ores, has a light yellowish-gray colour, is very hard, and is

[1] *Statistisches Jahrbuch des k. k. Ackerbau Ministeriums*, Vienna, 1882.

[2] *Ibid.* 1895, p. 146.

[3] F. M. Stapff, *Berg. und Hüttenm. Zeit.* 1865, p. 6.

[4] See page 367.

perhaps a metamorphosed eruptive rock. It accompanies the lode on both sides to a width of from two to fifteen fathoms, and gradually passes into ordinary slates, its thickness being greatest near the surface, and decreasing in depth. The normal Silurian clay slate is locally known as *blauer Schiefer.* The term *wilder Schiefer* is here applied to all varieties of slate near which the ore deposit becomes compressed and unproductive. The metalliferous minerals are regularly distributed in the *Lagerschiefer,* which is likewise impregnated with pyrites, which occurs in compact masses associated with quartz. The ores are either disseminated through the veinstones, or else copper pyrites and spathic iron ore occur in lenticular masses enclosed in quartz; it is to be remarked also that the longitudinal axes of these masses are not always parallel to the walls of the deposit, but are inclined towards them at varying angles. Sometimes, but not often, quartz and copper pyrites, but never copper pyrites and spathic iron ores occur in concentric bands; arsenical fahlerz and cinnabar occur as curiosities. On smelting the ores a certain proportion of nickel is obtained. The Mitterberg mines were the only copper mines in operation in Salzburg in 1894.

The total production of Salzburg during the year 1881 was, gold ore 84 tonnes, copper ore 3,152 tonnes, iron ore 3,837 tonnes, and nickel ore 40 tonnes, having an aggregate value of £17,550. In 1894 it was, gold ore 84 tonnes, copper ore 5,885 tonnes, iron ore 7,278 tonnes, total value £23,554.

TYROL.—The date[1] of the earliest mines in the Tyrol cannot be fixed with absolute certainty; the oldest are those about Kelchalpe near Kitzbühel. Silver mining was carried on at Trient in the tenth century, and the following centuries saw numerous other silver and gold mines opened up. Lead and silver were mined at the Schneeberg, thirty miles south-west of Innsbruck, in the fourteenth century, and mining for copper and silver was commenced at Schwaz in Northern Tyrol about 1409; almost at the same time mines were opened at Brixlegg, Mitterberg, and Kitzbricht. Mining at these places was flourishing in the fifteenth and sixteenth centuries, while at Schwaz, in 1519, 200,000 gulden were paid as royalty alone. At the begining of the sixteenth century, these mines are said to have employed 7,000 workmen. Mining was abandoned during the Thirty Years' War, and was not resumed until the eighteenth century, but it

[1] Max v. Isser Gaudententhurm, *Die Montanwerke Tirols. Berg. u. Hüttenmännisches Jahrbuch,* xxxvi. 1888, p. 226.

never again reached its former importance. The copper and silver mines at Klausen originated in 1497.

One of the best examples of the occurrence of bedded veins of auriferous quartz in rocks of Palæozoic age is that of the Heinzenberg, near Zell,[1] where beds and veins of quartz are enclosed in gray Silurian clay slates. Gold is never found in the veins, while in the bedded deposits it almost constantly occurs. Nine of these deposits are known, coursing from 11° to 26° north of west, dipping at an angle of from 65° to 70° towards the south, and having a thickness varying from a few inches to six fathoms. The bedded deposits consist of auriferous quartz and slates, the gold being either met with as dust-like enclosures, or, more rarely, in distinct leaves and grains. From a mining point of view the Friedrich bed is not of very great importance, although in former times the Anton and Johann beds were extensively worked. In the Friedrich deposit there are, however, several beds, varying from sixty to seventy fathoms in width, separated by unproductive strips, and traversing it in a diagonal direction, which contain workable gold quartz.

Since its commencement in 1439, the production of the Zell gold mines has always been very variable. From 1794 to 1815, with forty-two workmen, 120 oz. to 160 oz. of gold were annually produced, and from 1840 to 1847 the average yield was $152\frac{1}{4}$ oz. per annum. From 1848 to 1852 the annual production of gold was $184\frac{3}{4}$ oz., but in the year 1854 it increased to 212 oz. In 1866, 184 tonnes of gold quartz, 620 tonnes of rough-work, and 555 tonnes of slate were raised, giving 272 oz. of gold. In 1881, thirty-one miners were at work principally exploring, so that no ore was raised. In 1869, at a depth of 250 metres very heavy feeders of water were encountered, and the Heinzenberg mine closed down after a period of activity of over four centuries. It was re-opened some ten years later, but the results obtained were not satisfactory and it had to be closed again in 1885. No gold or silver ore has been produced from this district within recent years.

There are four mines in the Brixlegg[2] district, namely, at Schwaz, at the Kleinkogel, Grosskogel, and at the Matzenköpfel.

At Schwaz the veins, which vary in thickness from $\frac{1}{2}$ to 1 inch, occur in a grauwacke slate, and are filled with spathic iron ore,

[1] A. R. Schmidt, *Berg. und Hüttenm. Zeit.* 1868, p. 11.

[2] F. M. Stapff, *Berg. und Hüttenm. Zeit.* 1862, p. 134. *Oesterr Zeit.* xxix. 1881, p. 576.

ankerite, heavy spar, galena, fahlerz, copper pyrites, bournonite, pyrargyrite, and quartz.

The Kleinkogel has been worked, without interruption, from very ancient times, and is now supposed to be nearly exhausted; the Grosskogel, like the Schwaz Mines, has been resumed after a long interruption of operations. The Kleinkogel is situated on the southern border of the Unterinnthal, about two miles south-west of Brixlegg, where the Guttenstein limestone is traversed by numerous irregular fissures containing ores. Heavy spar associated with calc spar, ankerite and quartz, forms the principal gangue. An antimonial fahlerz, containing quicksilver, nickel and cobalt, sometimes traverses the heavy spar in irregular threads. Stapff endeavours to explain the deposits of ore at the Kleinkogel by an influence of the country rock. The deposits of the Grosskogel are irregular stockworks, sometimes of considerable extent, containing fahlerz, argentiferous copper and iron pyrites, heavy spar, calc spar, dolomite, and quartz.

At the Matzenköpfel, near Brixlegg, where the mining is of recent date, the lodes occur in Partnach dolomite, and contain argentiferous fahlerz, galena, and iron pyrites, with arsenides of nickel and cobalt, pyrargyrite, native silver, bituminous slate, dolomite, and calc spar.

From 1877 to 1880 the Brixlegg mines produced—

Ore for the smelter	1,240	tonnes.
Ore for the stamps	8,982	,,
Heavy spar	646	,,
Spathic iron ore	1,140	,,

From 1881 to 1886 the production was—

Copper and silver ores for smelting	998	tonnes.
Ores for concentration	5,506	,,
Heavy spar	538	,,
Iron ores	1,006	,,

The Pfunderrerberg, at Klausen,[1] consists of mica schist, in which there occurs a large mass of diorite. At the contact of these two rocks is a felstone-porphyry, of which the limits are not sharply defined. Three lodes traverse these rocks with a strike between 30° north of east and due east, and dip from 60° to 80°

[1] A. R. Schmidt, *Berg. und Hüttenm. Zeit.* 1867, p. 267. *Oesterr. Zeit.* xxix. 1881, p. 577.

towards the north; they are accompanied by numerous strings and exhibit the character of complex lodes sixteen fathoms in thickness. The country rock has a remarkable influence on the contents of the lodes, which are invariably richest in the diorites, where they contain argentiferous galena, blende, copper pyrites, and iron pyrites; while in the felstone-porphyry and slate, galena is entirely absent, and only copper pyrites and iron pyrites occur. Immediately the lodes pass into the slates they become impoverished. This mine, on account of the scarcity of timber and other materials, is not extensively worked, and as a rule only about fifteen men are employed. In 1894 there were got 181 tonnes of iron pyrites carrying gold, silver and copper, and valued at £145.

The Schneeberg[1] lies about thirty miles south-west of Innsbruck, and forms the point of intersection of several lofty mountain chains. Near its summit, 7,200 feet above the sea level, and just below the general level of the glaciers, is the Schneeberg Mine. There is reason to believe that this mine was worked for argentiferous galena and copper ores as early as the beginning of the fifteenth century. In 1486 a thousand miners were employed, but shortly afterwards the ores became exhausted, and operations were abandoned.

A new examination of this locality, in the years 1868 and 1869, led to the re-opening of the mine for the sake of the blende remaining untouched in the veins, and accumulated in large quantities both in the attle, or packing, and in the old waste heaps. Deposits of blende with galena occur in a mica schist containing garnets, which constitutes the rock of the Schneeberg. Although, however, the mica schist beds in the vicinity of the mines strike with remarkable regularity directly eastward, and dip towards the north, the deposits themselves, as well as the immediately adjacent mica schist beds, have a strike to the north-east, and a dip to the north-west. They vary in thickness from 6 to 55 feet, and consist of veinstone, blende and galena, with a little iron pyrites and chalcopyrite; ankerite, calcite, quartz, garnet and hornblende are usually present. The workings extend for a distance of 1,200 fathoms along the strike, and to a depth of 520 fathoms on the dip. The deposits are repeatedly dislocated by faults.

The author of the official report on Austrian mines, published in 1878 in connection with the French Exhibition of that year, was of opinion that Schneeberg was capable of annually producing

[1] F. Pošepny, "Notice sur quelques-unes des Principales Mines de l'État Autrichien," 1878. *Oesterr. Zeit.* xxvii. 1879, p. 106.

7,000 tonnes of blende containing 45 per cent. of zinc, and 3,000 tonnes of galena. It however appears that these anticipations have not hitherto been fully realised, for, although between five and six hundred men are employed, the production from 1877 to 1880, inclusive, was only 3,024 tonnes of blende containing 45 per cent. of zinc, and 27,133 tonnes of mixed ores containing 25 per cent. of that metal. From 1881 to 1884, the average annual production was 787 tonnes of the former and 15,675 tonnes of the latter class of mineral.

In 1881 Schneeberg produced 4,234 tonnes of zinc ore, this increased production being due to the erection of improved dressing apparatus.

Near Kitzbühel,[1] in Tyrol, bed-like lodes occur in Silurian clay slates and grauwackes. F. M. Stapff[2] describes these deposits as *Lagergänge*, or bedded lodes; A. R. Schmidt[3] calls them *Lager*, beds.

The copper pyrites occurring in Silurian clay slates has been worked for many years at the mines of Kupferplatte, Kelchalpe, and Schattberg; the ores principally consist of copper pyrites associated with iron pyrites in a gangue of quartz and ankerite, which often attains a thickness of several yards.

At the Kupferplatte Mine, five miles south of Kitzbühel, eight parallel bedded lodes varying from 4 to 35 feet in thickness are known to exist above one another, the quartz occurring in lenticular masses in the slate, while lenticular masses of slate are found in the quartz. In this lode copper pyrites and, more rarely, iron pyrites also occur either in the form of lenticules or in disseminated grains. Where the ores are rich, the country rock is composed of *Lagerschiefer;* but where, on the contrary, they are poor, the country rock is formed of the so-called *wilder Schiefer*, which is dark with an irregular cleavage. According to Stapff, the *Lagerschiefer* and *wilder Schiefer* enclosing the ore occur in a lenticular mass in normal Silurian clay slates.

The mine of Kelchalpe is ten miles south of Kitzbühel, and is 5,050 feet above the sea level. Copper pyrites here predominates, quartz being a subordinate material.

The Schattberg Mine, half a mile south of Kitzbühel, is worked by means of two adits and an inclined shaft, of which the perpendicular depth is about eighty fathoms.

[1] *Oesterr. Zeit.* xxix. 1881, p. 583.
[2] *Berg und Hüttenm. Zeit.* 1865, p. 18.
[3] *Ibid.* 1870, p. 174.

From 1877 to 1880, inclusive, the average production per annum from the Kitzbühel copper mines was as follows :—

	Rough-Work.	Percentage of Copper.	Ore.	Percentage of Copper.
	Tonnes.		Tonnes.	
Kupferplatte	1,358	1·09	142	10·5
Kelchalpe	3,436	1·57	384	14·0
Schattberg	962	1·56	126	12·3

whilst the results obtained from 1881 to 1886 were :—

	Rough-Work.	Percentage of Copper.	Ore.	Percentage of Copper.
	Tonnes.		Tonnes.	
Kupferplatte	1,372	0.59	97	8·37
Kelchalpe	2,838	2·82	455	17·05
Schattberg	1,788	2·04	292	15·27

The total production of Tyrol in 1881 was :[1]—

	Tonnes.	Value.
Silver ore	0·5 . . .	£75
Copper ore	12,734 . . .	£9,522
Iron ore	1,706 . . .	£1,239
Lead ore	515 . . .	£4,822
Zinc ore	4,537 . . .	£9,965
Sulphur ore.	779 . . .	£389

In 1894 [2] it was :—

	Tonnes.	Value.
Copper ore	1,340 . . .	£7,348
Iron ore	4,657 . . .	£2,349
Lead ore.	182 . . .	£1,526
Zinc ore	2,995 . . .	£7,841
Sulphur ore	181 . . .	£145

Carinthia and Styria.—Certain limestones of the Carinthian Alps contain in various localities deposits of lead and zinc ores, which, notwithstanding slight differences in detail, resemble one another in their more important characteristics, and have doubtless a common origin. The principal localities where such deposits have been worked are the following, namely :—Bleiberg, Kreuth, Raibl, Windisch-Bleiberg, Kappel, Mies and Schwarzenbach. They all occur in a belt of limestone of a few miles in breadth and about seventy-five miles in length; but it will be unnecessary to give a description of more than one of them.

[1] *Statistisches Jahrbuch des k. k. Ackerbau Ministeriums*, Vienna, 1882, p. 135.

[2] *Ibid.* 1895, p 146.

The mining village of Raibl,[1] in Upper Carinthia, is situated on a declivity of the Königsberg, which contains deposits of galena, blende, and calamine, which have been worked from the earliest times. The deposits of Raibl rest conformably on the strata of the Upper Trias, and have been displaced to a distance of from twenty to thirty fathoms by faults running north and south. Near these dislocating fissures, which, at the surface, can be distinguished as valleys, the ores occur in limestone, chiefly in its upper portions; the term limestone is, however, purely a stratigraphical distinction, since these beds, 1,000 yards in thickness, are not only composed of limestone but also of various slates and dolomites. The Raibl beds, resting on the limestone, consist of marl, slate, and shale. Galena and blende occur in the dolomite, while the calamine deposits are found on a somewhat different horizon in the limestone. The deposits of galena and blende are distinctly cavities in the dolomite and dolomitic slates which have been filled by infiltration or substitution. They are very irregular in form, but always contain crystalline blende, galena, iron pyrites, and dolomite, in layers parallel to the walls of the deposit. Dolomite sometimes occurs between the galena and blende, and seems most frequently to form the central lining of the cavity, but in some cases blende occupies this position. Heavy spar is rare, and never forms entire beds, but occurs only as separate crystalline aggregations in dolomitic geodes. The calamine deposits differ entirely from the foregoing, as in them there is nothing to indicate cavities filled by infiltration, but everything, on the contrary, seems to show that they are metasomatic after limestone, and certain peculiarities of this rock are accurately reproduced in the calamine. At Raibl the calamine consists, principally, of zinc carbonate and, more rarely, of zinc bloom, while silicate of zinc is very rare. The ore most plentifully obtained is a nearly pure zinc carbonate, containing on an average 45 per cent. of zinc. The production of ore in 1876 was 18,411 tonnes, but in 1880 it sank to 9,794 tonnes. From 1881 to 1886 it averaged 2,483 tonnes of 38 per cent. calamine, 1,270 tonnes of 40 to 43 per cent. zinc blende, and 590 tonnes of 60 to 69 per cent. galena per annum. In 1894 the Raibl mines produced 9,175 tonnes of zinc ore, consisting of calamine and zinc blende in about equal proportions, and 1,342 tonnes of concentrated lead ore.

The Noric iron of Tacitus and other classic authors was prepared from ores obtained in the Styrian Erzberg, and, as this

[1] F. Pošepny, *Jahrb. d. k. k. geol. Reichsanst*, xxiii. 1873, p. 317. *Oesterr. Zeit.* xxix. 1881, p. 584.

industry has, without intermission, continued in activity from the date of the Roman occupation to the present day, the aggregate yield must have been enormous. A fire which took place at Eisenerz in 1618, destroyed documents then existing which carried back the iron manufacture to A.D. 712, but the documents still preserved do not go further back than the twelfth century. In 1871 Styria with thirty-one blast furnaces, produced 122,000 tonnes of pig iron, and during the same year Carinthia yielded 63,000 tonnes from seventeen furnaces.

The total production of iron ore in Styria during the year 1881 amounted to 420,974 tonnes, worth £109,042. Carinthia in the same year produced 88,041 tonnes of iron ore, worth £35,486[1]. These two districts produced 143,560 tonnes and 32,448 tonnes of iron ore respectively in 1894; the returns of pig and bar iron for the year were respectively 170,405 and 41,545 tonnes.

CARNIOLA.—The quicksilver deposit of Idria,[2] in Carniola, was discovered in 1490, or according to others in 1497, by a cooper, who formed a company for the purpose of working it; and mining was carried on by this and other companies until the Government took charge of the property in 1580. Recent investigations relative to the geology of Idria, by M. V. Lipold, the present manager, have shown that the ore-bearing rocks are exclusively of Triassic age, and that the carboniferous sandstones and schists which form the roof of the metalliferous beds have only assumed this position through dislocation, displacement or reversal.

In the north-western portion of the mine the deposit possesses the character of a bedded vein enclosed in the so-called *Skonca* beds and conglomerates, and is of the nature of a stockwork in a Lower Triassic breccia. The ore in the south-eastern part occurs chiefly in fissures in Lower Triassic Guttenstein limestone and dolomites, both hanging and foot-wall being impregnated with cinnabar. In the north-western part of the mine, in which the *Wengen* beds follow the course of the main dislocating fissure, *Guttenstein* and *Werfen* beds consisting of dolomites, limestones, and of sandy slates on which the *Wengen* beds are deposited, form the foot-wall of the deposit. Above the *Wengen* beds come the *Skonca* beds, and above these are limestone-conglomerates impregnated with cinnabar, dolomitic breccia, and *Guttenstein* beds. The *Wengen* beds, which principally carry the ore, dip 42° north-east,

[1] *Statis. Jahrbuch*, 1882, p. 33.

[2] M. V. Lipold, "Das k. k. Quecksilber-werk zu Idria in Krain," published in 1881, to commemorate the 300th anniversary of the Government possession. *Oesterr. Zeit.* xxx. 1882, p. 84.

until at a depth of 150 fathoms they split up into two branches, rising respectively for a distance of forty fathoms at angles of 34° and 47°, and then, turning downwards, are united, and assume a dip of 50° north-east. The slates are not uniformly impregnated with cinnabar, there being sometimes rich pockets and lenticular masses enclosed in barren ground. Cinnabar is the only ore occurring in depth, native quicksilver being found only near the surface.

The richest ore is the *Stahlerz* or steel ore, so called from its colour, which contains 75 per cent. of mercury and occurs in a compact or crypto-crystalline form. The *Lebererz* is liver-coloured, compact and lustrous, usually forming nests in the *Stahlerz*. The *Ziegelerz*, or brick ore, is sandy, granular, and of a bright red colour. A peculiar variety of the ore is know as *Korallenerz*.

The *Skonca* beds proper consist principally of dark, bituminous, dolomitic sandstones and slates, containing fossils resembling corals, which have not at present been determined; these coral sandstones and slates are sometimes productive of ore. The slates, where they carry ore, which is frequently associated with iron pyrites, are generally highly bituminous. In the south-eastern parts of the mines the strata are almost vertical, and are crossed by fissures sometimes exceeding three feet in width. The quicksilver deposit of Idria contains iron in the form of pyrites, but no other metals, and is remarkably poor in crystallised minerals; cinnabar, calc spar, dolomite and quartz being rarely found as good crystals. Idrialite and anthracite occur in the form of compact masses.

Lipold believes that the ores owe their origin to infiltration from below, and calls attention to the fact that the mine grows richer as greater depth is attained.

From 1877 to 1886 the reduction works treated the following quantities of ore:—

1877.	33,311	tonnes	containing	1·371	p.c.	of mercury.
1878.	33,004	„	„	1·360	„	„
1879.	40,627	„	„	1·076	„	„
1886.	64,289	„	„	0·850	„	„

The production of quicksilver in 1877 amounted to 837,960 lbs., while the yield in 1878 and 1879 amounted respectively to 791,015 and 924,137 lbs. Within the last thirty years the production of Idria has been trebled. In 1894 the production was 84,128 tonnes of ore valued at £98,875, and yielding 519 tonnes of quicksilver, being a slight improvement on the previous year, but a falling off from 1891, when 570 tonnes were produced. Among the quicksilver mines of the world, Almaden, in Spain, takes the first rank, New Almaden, in California, the second, and Idria, in Carniola, the third.

General Summaries of the Production of Metalliferous Minerals in the Austrian Empire, exclusive of Hungary.

For the Year 1882.[1]

Description of Ore.	Quantities.	Values.	
	Tonnes.	Gulden.	£[2]
Iron ore	902,510	2,397,464	239,746
Tin ore	2,602	20,063	2,006
Copper ore	4,154	229,036	22,904
Lead ore	14,765	1,172,847	117,285
Zinc ore	25,300	374,093	37,409
Sulphur ore	9,005	101,012	10,102
Gold ore	354	16,839	1,684
Silver ore	11,841	3,043,935	304,394
Nickel and Cobalt ores	14	528	53
Antimony ore	509	22,232	2,223
Bismuth ore	21	—	—
Uranium ore	6	39,144	3,914
Wolfram	66	8,936	894
Quicksilver ore	46,968	543,005	54,300
Manganese ore	8,418	74,124	7,412
Total value of Metalliferous Minerals produced in 1882		8,043,258	804,326

For the Year 1894.[3]

Description of Ore.	Quantities.	Values.	
	Tonnes.	Gulden.	£[2]
Gold ore	86	9,907	991
Silver ore	18,338	3,000,171	300,017
Quicksilver ore	84,128	988,754	98,875
Copper ore	7,235	278,849	27,885
Iron ore	1,214,736	2,676,114	267,611
Lead ore	12,061	836,744	83,674
Nickel and Cobalt ores	55	?	?
Zinc ore	28,491	439,780	43,978
Tin ore	24	2,465	247
Bismuth ore	570	15,194	1,519
Antimony ore	686	68,632	6,863
Arsenic ore	2	100	10
Uranium ore	26	59,404	5,940
Wolfram ore	40	10,908	1,091
Sulphur ore	2,435	34,484	3,448
Vitriol and Alum shales	10,854	13,495	1,350
Manganese ore	5,055	55,417	5,542
Total value of Metalliferous Minerals produced in 1894		8,490,418	849,041

[1] From the *Statistisches Jahrbuch des k. k. Ackerbau Ministeriums für* 1882, Vienna, 1883.

[2] The gulden is taken at 2*s*.

[3] *Id. für* 1894, p. 146.

Hungary.

Mining in Hungary dates from before the time of the Romans, when important gold mines were in operation in Dacia, the Transylvania of the present day, at Vöröspatak, Zalathna, and Offenbánya, while, in Lower Hungary, silver and copper mines were opened in the seventh century. The town of Schemnitz was founded about the beginning of the twelfth century by Frank and Saxon miners; Kremnitz is of nearly the same date, while Neusohl was founded in the fourteenth century by miners from Saxony and Thuringia. In Upper Hungary mining for silver, copper and antimony originated at Schmöllnitz, Aranyidka and Kapnik, by German colonisation in the fifteenth century, the gold mining at Botza, in Lower Hungary, dating from 1550. The Schemnitz mines, which still continue to be the most important, in the year 1690 produced 16,894 oz. of gold; while the production of precious metals from 1740 to 1773 was not less than seventy million gulden; in 1881 the annual production was about 16,241 oz. of gold and 378,962 oz. of silver, and ten years later about 14,000 oz. of gold and 453,000 oz. of silver. In Southern Hungary important lead and silver mines existed at Gvosdanska, but they were abandoned in the middle of the sixteenth century on account of the wars with the Turks.

At Schemnitz,[1] in the mining district of Neusohl (Besztercze-bánya), sixty-five miles north-west of Buda, the lodes pass in a south-westerly direction out of propylite into beds of Miocene age, thus proving that they were formed at a comparatively recent date. These lodes are characterised by great width, and by a filling consisting of decomposed and altered rocks in which the ores occur as impregnations, in threads, and as the cementing material of breccias. Distinct selvages do not occur, and the veins consequently appear rather as bands of rock impregnated with ore than as fissures which have been filled with various mineral substances. The veinstone varies considerably in the different lodes, but rocks converted into a clayey or siliceous mass, hornstone, quartz and amethyst, are of especially frequent occurrence. A peculiar quartzose rock, locally known as *Sinopel*, which is of a brownish-red colour, probably owing to the presence of iron oxide,

[1] M. V. Lipold, *Jahrb. d. k. k. geol. Reichsanst.* 1867, p. 317.

is rich in gold besides being impregnated with argentiferous galena, blende, copper pyrites, and iron pyrites.

Among the minerals occurring in the lodes are various rich silver ores, such as native silver, polybasite, pyrargyrite, &c., which are found, principally, in veins enclosed in the syenite at Hodritsch, near Schemnitz, but also occur, although more rarely, at Schemnitz itself. At Hodritsch a small mass of syenite comes to the surface, and is surrounded on all sides by propylite. J. W. Judd and G. v. Rath question whether this rock is really a syenite, but Pettko, Adrian, and Lipold are of opinion that it is so. The syenite of Hodritsch has a much greater extent beneath the surface than at the surface, and is surrounded by metamorphosed Devonian strata, and by rocks of Triassic age. The Tertiary eruptive rocks burst through the syenite and sedimentary rocks in lode-like dykes, and extend in great masses over both. Propylite is the oldest Tertiary eruptive rock found in the neighbourhood, and this, as in other Hungarian metalliferous districts, is penetrated by more recent igneous rocks. At Schemnitz dykes of rhyolite sometimes occur as productive metalliferous veins. According to Lipold, the Grüner Lode, the Johann Lode and the Biber Lode are nothing more than veins of rhyolite which contain silver and other ores in strings and fissures, and he is of opinion that the mode of distribution of the ore would lead to the theory of a subsequent infiltration of minerals into the igneous veins. In the syenite are veins of dacite which, as they accompany the lodes, may possibly have opened the way for their formation. The relative ages of the rhyolitic veins in the propylite and of the dacite veins in the syenite yet remain to be determined, but a very large number of lodes are known to exist within the limits of these rocks. Generally speaking, the veins in syenite have a more irregular strike, namely from south-west to north-east, from north to south, and even from east to west, than have the veins in the propylite, which course principally from south-west to north-east. The dip is usually about 75° towards the south-east, but occasionally towards the north-west. Several of the veins may be followed for a great distance in the direction of their strike. The Grüner Lode can be traced for above 1,000 fathoms, and the Spital Lode for about half a mile, so that this lode, with its great thickness of twenty fathoms, is one of the largest in the world.

Among the more recent minerals found in these lodes may be mentioned calc spar, brown spar, diallogite, spathic iron ore, heavy spar and gypsum. The ores are to a large extent concentrated in columnar or irregularly formed shoots, which differ in character not only in the various lodes but frequently also in the same fissure. In this way the north-east portions of the Spital Lode contain only gold, galena, blende and copper pyrites, galena playing the principal part, while in the south-west portions silver ores almost exclusively prevail. The most productive lodes in Schemnitz, namely, the Grüner Lode, the Stefan Lode, the Johann Lode, the Spital Lode, the Biber Lode and the Theresia Lode, occur in propylite. The most important of these are the property of the State and their production[1] in 1893 was 44,240 tonnes of ores of all kinds containing 211 kilogr. gold, 5,564 kilogr. silver, 890 tonnes of lead and 22 tonnes of copper.

Kremnitz,[2] eighteen miles north of Schemnitz, is one of the most ancient of the Royal Free Mining Cities of Hungary. Here a mass of propylite, surrounded by gray trachyte, is traversed by numerous veins which are so intermixed with the country rock that in places neither their strike nor their dip can be determined. The mass of propylite is about half a mile in length and from 1,000 to 2,000 fathoms in width, and contains finely disseminated auriferous pyrites, which becomes concentrated in the vicinity of veins and fissures. Although the deposit generally presents rather the appearance of a stockwork than of a regular lode, yet, strictly speaking, this is not a correct definition, since enclosed in the propylite are two distinct and parallel groups of lodes, coursing from north to south, which are known respectively as the Main Lode group and the Georg-Sigmund group.

The former includes the Main Lode, the Schrämer Lode, the Kirchberg Lode, the Schindler Lode and the Katharinen Lode; these lodes are connected together by numerous flucans and branches. The lodes of this group dip from 45° to 55° east; the branches of the hanging wall, however, always incline at a greater angle than the foot wall, so that the entire system of lodes converges in depth, thus somewhat resembling an open fan. Fig. 93, after Windakiewicz, represents a section across these lodes. Their thickness varies from three to five fathoms, and, at the point where the branches meet, is sometimes as much as 50 fathoms across. The filling principally consists of quartz or hornstone with decomposed country rock, and intermixed with the quartz is finely divided argentiferous and auriferous pyrites, which imparts to it a grayish colour.

[1] Carl Déry, *Ungarisches Montanhandbuch*, 1896, p. 18.
[2] E. Windakiewicz, *Jahrb. d. k. k. geol. Reichsanst.* xvi. 1866, p. 217.

The Georg-Sigmund group consists of the Lettengang, dipping 65° west, and the Georg-Sigmund Lode, on the hanging side of the latter, dipping 70° east. The filling is, for the most part, the same as that of the previous group, except for the occurrence in the latter of auriferous stibnite and metallic gold. Among the minerals frequently found in the lodes may be mentioned quartz, calc spar, brown spar, heavy spar, auriferous and argentiferous iron pyrites, stibnite, fahlerz, pyrargyrite, and argentite; while arsenical pyrites, blende, galena, copper pyrites, and cinnabar are rare. In consequence of the decomposition of pyrites the outcrops of the lode were especially rich in gold. These mines too are the property of the State and produced in 1893 [1] a total of 17,015 tonnes of ore, worth £5,104.

At Nagybánya,[2] in South-eastern Hungary, the lodes occur in propylite, and only occasionally in gray trachyte, which is pene-

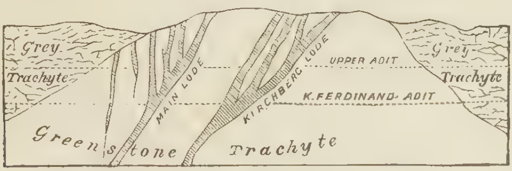


FIG. 93.—Section of lodes, Kremnitz.

trated and superstratified by the former, their strike being 30° to 45° east of north. The most important of these lodes is the Kreuzberg, which courses north and south, dips from 70° to 80° west, has an average thickness of three feet, sometimes increasing to six feet, and traverses the mountain of the same name from its summit to its base. The lodes generally are not well defined and have no selvages. The filling consists of quartz, in which the auriferous pyrites, with a little copper pyrites, is finely disseminated, but nests of silver ores, especially of pyrargyrite and argentiferous fahlerz, also occur. It is remarkable that at the Kreuzberg the various carbonates are entirely absent, as are also heavy spar, galena, blende, stibnite and realgar, which in other places are so frequently found in similar lodes. Near Nagybánya are the mines of Felsŏbánya, Kapnik, and Oláh-Lápos-Bánya.

Near the village of Felsŏbánya is situated the Grossgruben Mountain, which consists principally of propylite, and is at the foot

[1] *Ungarisches Montanhandbuch*, 1896, p. 19.

[2] F. v. Richthofen, *Jahrb. d. k. k. geol. Reichsanst.* 1860, p. 238. B. v Cotta, *Berg. und Hüttenm. Zeit.* 1861, p. 81.

surrounded by Tertiary beds. The lodes occur in this propylite striking east and west, and in the direction of their rise open out like a fan, in such a way that at the surface the group has a breadth of no less than 240 fathoms, but gradually narrows down as it gets deeper. These lodes have a thickness varying from one to twelve fathoms, and a dip of from 45° to 70°. Impure quartz containing disseminated pyrites and other minerals is the oldest and most important veinstone, and is very rarely absent, but when it is so, realgar and stibnite often occur in fine crystals. Above the quartz come auriferous pyrites, argentiferous galena, blende, copper pyrites, stibnite, realgar, and argentite. Then follow heavy spar and gypsum; while among the most recent minerals are calc spar and brown spar.

The lodes at Kapnik[1] are very similar to those above described, but here two systems of veins are distinguished. Those of the older, like those of Felsőbánya, course east and west, and occur in a conglomerate lying at the boundary of the propylite and gray trachyte. The filling material resembles that of the parts of the Felsőbánya lodes which are poor in quartz, but when quartz is entirely wanting the ores lie directly upon the altered rock. The more recent system of lodes courses, like the Nagybánya lodes, 30° to 45° east of north, and their thickness varies from one inch to seven feet. Quartz and pyrites have impregnated the country rock, and blende and galena occur in threads. The lodes often contain large druses, in which are found the magnificent crystallised minerals for which Kapnik is celebrated.

At Oláh-Lápos-Bánya the propylite has exercised a metamorphic action on the Tertiary beds, and the lodes, as far as they occur in that rock, are exactly similar to those of Kapnik; but where they traverse Tertiary strata they only contain quartz with a small quantity of pyrites.

Magurka[2] is situated on the northern border of the granitic chain, which, 4,000 to 6,000 feet above the sea, extends from Djumbir in a westerly direction, and the mine is worked at an altitude of from 2,500 to 3,000 feet. Several lodes containing stibnite, quartz, and native gold occur in the granite; but of these the most northerly only is worked. It varies in width from a few inches to twelve feet, dips at an angle of from 25° to 30°, and is much dislocated by faults. The granite in the neighbourhood of

[1] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1861, p. 189. H. Höfer, *Jahrb. d. k. k. geol. Reich.* 1866, p. 1.

[2] R. Meier, *Jahrb. d. k. k. geol. Reichsanst.* 1868, p. 257.

the lode has undergone much alteration, the felspar being converted into a greenish-yellow wax-like mineral, and the mica, originally dark, having become silver-white. The filling principally consists of quartz, stibnite and granite, while argentiferous gold is finely disseminated in the quartz. Galena, blende, pyrites, brown spar and calc spar occur subordinately. At the richest points the stibnite is disseminated over a width of more than six feet, and the ore contains enclosed fragments of granite. At one point the lode is symmetrically filled in with stibnite in the middle and quartz on both sides of it, accompanied, on one side, by a brown spar string of more recent formation.

At Schmöllnitz[1] a zone of clay slate is interstratified with mica schists, and encloses beds containing patches and compact lenticular masses of iron pyrites. The clay slate zone, which is about 1,200 feet in thickness, courses from east to west, dips from 60° to 75° towards the south, and is worked for a distance of about three miles along its strike. In the floor and roof of the zone of clay slate, which may be regarded as the ore deposit, there is a black carbonaceous slate containing a large proportion of silica. The gray clay slates of this bed enclose two principal metalliferous zones, varying from six to sixty feet in thickness, containing pyrites, but they are not distinctly separated from the gray slates, as they always contain more or less sulphides. The ores are principally iron and copper pyrites, partly separated out as crystals in the slate, and partly as compact masses more or less associated with quartz. The latter often appear as lenticular bodies of variable dimensions enclosed in clay slates.

Three large lenticular masses of pyrites, known respectively as the *Liegend-Kiesstock*, the *Hangend-Kiesstock*, and the *Engelberti-Kiesstock*, are especially remarkable. The largest of these lenticular masses is the Liegend-Kiesstock, which is 210 fathoms along its strike, 75 fathoms in the direction of its dip, and 19 fathoms in thickness. The Hangend-Kiesstock may be followed for a distance of 142 fathoms along its strike, and 63 fathoms on its dip, while its thickness is 7 fathoms. The Engelberti-Kiesstock has a length of 160 fathoms, a width on its dip of 40 fathoms, and a thickness of 15 fathoms. These deposits are accompanied by shales impregnated with pyrites, and in the eastern portion of the zone traces of galena, blende, and various ores of cobalt have been discovered.

At Herrengrund,[2] near Neusohl, very irregular deposits occur

[1] G. Faller, *B. u. H. Jahrb. d. k. k. Oesterr. Bergacad.* xvii. 1868, p. 193.
[2] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1861, p. 58.

in the gneiss, mica schist and grauwacke slates, near their junction with the granite. The mineralogical constitution of the mass is here usually as irregular as its form. The so-called Pfeifer Lode appears to be a thick vein of spathose iron ore cutting obliquely through siliceous slate, and containing fahlerz either disseminated or in strings. In the southern portion of the field, bed-like lenticular masses of fahlerz associated with copper pyrites and quartz, from six to ten inches in thickness, lie between the foliations of a gneiss which passes over into a talco-micaceous schist.

At Dobschau,[1] gabbro, partially converted into serpentine, is surrounded by clay slates resting upon gneiss and granite. The lodes occur on the edge of the gabbro in the vicinity of the clay slates; they exhibit a fan-like arrangement, and possess the characteristics of composite lodes separated by no distinct boundary from the country rock. They sometimes attain a thickness of 24 feet, and are principally filled with country rock traversed by threads of ore. A compact mixture of copper and nickel ores is the mineral wrought; this contains from 17 to 22 per cent. of nickel, and from 4 to 10 per cent. of copper. Compact fahlerz, copper pyrites, erubescite, and nickeliferous pyrites are rare. Spathic iron ore, calc spar and ankerite accompany the ore as gangue.

Transylvania.[2]—The mining town of Nagyág, in Transylvania, is situated in a valley on the northern slope of a trachytic mountain range, twelve miles north-west of the town of Broos and lying between the rivers Maros and Aranyos. All the surrounding country is composed of propylite, which has burst through beds of Miocene age, consisting of limestones, sandstones, conglomerates and red clays. The propylite encloses large masses of Tertiary sandstones and conglomerates, which have experienced no apparent alteration. The lodes vary in thickness from a few inches to six feet, and their course is usually either north and south or south-east and north-west, with a dip at a considerable angle, thus forming a complicated network of veins. The ores occur in propylite, and both this rock and the enclosed sandstones and conglomerates are traversed by so-called *Glauch* lodes. This term the miner applies to eruptive masses or dykes enclosing angular fragments of the country rock, and of a peculiar slate which

[1] G. Faller, *B. u. H. Jahrb. d. k. k. Oesterr. Bergacad.* 1868, xvii. p. 165.

[2] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1861, p. 190. H. Höfer, *Jahrb. d. k. k. geol. Reichsanst.* 1866, p. 1.

contains rounded patches of quartz about the size of a nut. The *Glauch* of Nagyág is a rock closely resembling dacite. The *Glauch* lodes vary from an inch to three feet in thickness, and have generally a course similar to that of the ore-bearing lodes, on the productiveness of which they apparently exercise a favourable influence. The ore-bearing veins in the hard propylite are usually thin and unproductive, but when it is less hard they are thicker and more metalliferous; in a soft country rock they are commonly much split up. They traverse both the propylite and the *Glauch*. The most important minerals found in the lodes are quartz and hornstone, brown spar, calc spar, native gold, nagyagite, sylvanite, hessite, native tellurium, oxide of manganese, blende and iron pyrites. More rarely they contain gypsum with enclosed scales of gold, heavy spar, native arsenic, magnetic pyrites, copper pyrites, fahlerz, bournonite, galena, stibnite, plumosite, blende, realgar, orpiment and native sulphur. In the propylite are found nagyagite, alabandite, diallogite, with, subordinately, galena, blende, argentiferous fahlerz and quartz: in the conglomerates, on the other hand, sylvanite, quartz and fahlerz are found.

Offenbánya,[1] is situated north-west of Abrudbánya, in the Transylvanian Erzgebirge, between the rivers Aranyos and Maros. Here fissures about one inch in thickness traverse much-weathered propylite, and contain free gold with ores of tellurium associated with quartz, calc spar, brown spar, diallogite, iron pyrites, blende, fahlerz, galena, native silver and pyrargyrite. These so-called tellurium veins are obliquely traversed by others containing quartz and iron pyrites, which have a favourable influence on their productiveness.

The workings which have opened up the tellurium veins, have also passed through an adjacent granular limestone containing massive deposits of ore. The form of these is very irregular, as they occur as nests, pockets, and threads, varying in size from the smallest patches to large masses. Among the ores contained in these deposits are iron pyrites, galena, blende, sulphide of manganese, psilomelane, fahlerz and stibnite. The principal earthy minerals are calc spar, brown spar, silicate of manganese, hornstone, quartz and clays. Grimm[2] states that a longitudinal arrangement of the minerals within the ore mass or in the lodes and cavities is exceptional.

The contact masses of Rodna occur under very similar geological

[1] Pošepny, *Jahrb. d. k. k. geol. Reichsanst.* 1875, p. 70.
[2] *Berg. und Hüttenm. Jahrbuch. d. k. k. Oesterr. Bergacad.* xvi. 1867, p. 306.

conditions to those of Offenbánya. The district is composed of mica schist and hornblende schist, with numerous intercalations of granular limestone. Tertiary beds also occur. Numerous masses of andesite burst through these rocks, and, where they come in contact with the granular limestone, ore deposits occur enclosed in the latter rock. The size of the ore bodies is very variable; the one which is at the present time principally worked has a vertical height of 278 feet, and a thickness of 92 feet. It has been explored for a length of 390 feet without the end having been reached. The ore is a mixture of iron pyrites, blende and argentiferous galena, consisting of 60 per cent. iron pyrites, 20—25 per cent. blende, and 6—8 per cent. galena, the remainder being calcite and quartz.[1] Arsenical pyrites and dolomite also occur. The ores contain gold and silver. Pošepny[2] determined the relative age of the minerals to be as follows:—(1) Iron pyrites and quartz; (2) galena, blende and arsenical pyrites; (3) dolomite and calcite. Von Beust[3] and Pošepny are of opinion that the Rodna deposit is of metamorphic origin, formed by the eruption of the andesite; while, on the other hand, Grimm[4] regards it as an ore deposit originally formed in the limestone, and subsequently split up by the eruption of the andesite.

The Transylvanian village of Vöröspatak[5] lies in a deep valley five miles north-east of Abrudbánya, and is built upon a sandstone recognised as of Eocene age. In a westerly direction the valley is closed by a crescent-shaped mountain ridge composed of a hornblendic rock generally regarded as propylite, which must be more recent than the Tertiary sandstone, which it has broken through. Towards the south rises the bare and rocky mountain ridge of Csétatje, composed of a much altered eruptive rock, probably propylite, which is impregnated with iron pyrites and traversed by innumerable irregular veins containing quartz, gold, iron pyrites, blende, fahlerz, magnetic pyrites, galena, berthierite, calc spar, spathic iron ore, &c. Black clayey masses, called *Glamm*, containing fragments of mica schist and sandstone, traverse the productive rock in the form of veins and threads. This productiveness is continued from the eruptive rocks into the adjacent Eocene

[1] G. v. Rath, *Zeitschr. d. d. geol. Gesellsch.* xxx. 1878, p. 556.
[2] *Jahrbuch. d. k. k. geol. Reichsanst.* 1865, p. 183, and 1870, p. 19.
[3] *Jahrbuch. d. k. k. geol. Reichsanst.* 1869, p. 367.
[4] *Berg. und Hüttenm. Jahrbuch. d. k. k. Oesterr. Bergacad.* 1870, p. 170.
[5] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1861, p. 173. F. Pošepny, *Jahrb. d. k. k. geol. Reichsanst.* 1867, p. 99. C. Doelter, *ibid.* 1874, p. 7.

sandstones, which are traversed by numberless fissures filled with quartz, auriferous iron pyrites, fahlerz, copper pyrites, calc spar, &c. Occasionally such fissures may be followed for more than 100 fathoms along their strike and 30 fathoms in the direction of their dip.

In 1873 no less than 416 mining companies were at work in the gold districts of Transylvania, giving employment to 8,369 miners who, although a considerably smaller number than was formerly employed, still made their living by this industry; in 1876, however, the number of companies was still further reduced to 383, employing 6,613 miners. In 1877 this region produced 27,870 oz. of gold, 20,108 oz. of silver, $4\frac{3}{4}$ tonnes of copper, and $1\frac{1}{4}$ tonnes of lead, of an aggregate value of £126,900.[1]

THE BANAT.[2]—The eruptive rocks of the Banat and Servia strike generally from north to south in a zone 190 miles in length. To these rocks, which are probably diorites, v. Cotta gives the collective name of banatites. They are accompanied by crystalline slates, by Jurassic rocks, and probably also by rocks of Cretaceous age. At the junction of the eruptive and sedimentary rocks, the limestones become crystalline, and enclose garnets, wollastonite, and vesuvianite. Associated with these rocks are irregularly formed contact deposits which contain iron pyrites, magnetite, and a great number of other minerals; among the sulphides, iron pyrites, copper pyrites and blende predominate. The most important and best known mining districts of this zone are those of Rézbánya, Moravicza, Dognazka, Oravicza, and Cziklova.

The deposits of Rézbánya have been well described both by Peters[3] and by Pošepny.[4] According to the latter the irregular ore deposits of this district represent cavities occurring as dislocating fissures. They occur in patches of Mesozoic limestone of ages varying from Liassic to Neocomian. The ore filling is mostly confined to the neighbourhood and sometimes to the immediate contact of eruptive rocks. A good example is at Reichenstein.[5] Peters gives a list of sixty-three different minerals occurring in these deposits.

The following tables illustrate the mineral production of Hungary:—

[1] *Oesterr. Zeitschr.* xxvii. 1879, p. 477.
[2] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1864, p. 118.
[3] *Berg. und Hüttenm. Zeit.* 1862, p. 269.
[4] *Jahrb. d. k. k. geol. Reichsanst.* 1875, p. 40.
[5] F. Pošepny, *Trans. Amer. Inst. Min. Eng.* xxiii. 1894, p. 288.

General Summaries of the Production of Metalliferous Minerals in Hungary during the Years 1881[1] and 1894.[2]

1881.

Description of Ore.	Quantities.	Values.		
	Tonnes.	Florins.	£[3]	s.
Iron ore	465,479	1,250,263	125,026	6
Copper ore	7,889	407,302	40,730	4
Lead ore	1,386	146,061	14,606	2
Zinc ore	1,462	38,591	3,859	2
Iron pyrites	47,129	206,890	20,689	0
Silver and Gold ore	6,267	706,939	70,603	18
Ores containing Gold, Silver, Lead and Copper	96,519	676,048	67,604	16
Cobalt and Nickel ore	137	79,214	7,921	8
Antimony ore	767	84,728	8,472	16
Quicksilver ore	2	350	35	0
Manganese ore	2,832	21,308	2,130	16
Total value of Metalliferous Minerals produced in 1881		3,617,694	361,679	8

1894.

Description of Products.		Quantities.	Values.	
			Florins.	£[3]
Gold	Kilogr.	2,687	4,497,627	449,763
Silver	,,	20,155	1,217,186	121,719
Copper	Tonnes	271	135,367	13,537
Lead	,,	2,113	295,015	29,501
Iron pyrites	,,	74,619	320,970	32,097
Iron ores (exported)	,,	237,476	751,845	75,185
Bar iron	,,	312,148	11,216,865	1,121,687
Pig iron	,,	17,837	1,397,922	139,792
Crude Antimony and metal	,,	385	124,642	12,464
Antimony ore	,,	1,266	68,733	6,873
Nickel and Cobalt ores	,,	24	8,106	811
Cobalt and Nickel alloy	,,	23	9,374	937
Litharge	,,	689	117,512	11,751
Ochre	,,	608	13,853	1,385
Manganese ore	,,	195	2,180	218
Mercury	Kilogr.	1,837	4,699	470
Tin	Tonnes	3	1,815	181
Bismuth	,,	28	2,520	252
Total value of Metalliferous Products for 1894			20,186,231	2,018,623

[1] Inclusive of all countries belonging to the Crown of St. Stephen, namely, Hungary, Transylvania, Kroatia-Slavonia, &c. From figures supplied by the Royal Hungarian Statistical Bureau.

[2] Bergwerks und Hütten. Production Ungarns, 1894; *Oesterr. Zeitsch. f. Berg. u. Hüttenwesen*, 1896, No. 6, p. 69.

[3] The florin is taken at 2 shillings.

ITALY.

Nearly the whole of the geological formations, both igneous and sedimentary, are, to some extent, represented in Italy, and among the former may be included the eruptive rocks now being poured forth from the volcanoes of Naples and Sicily. These different formations yield, more or less abundantly, various useful minerals. Italy contains deposits of iron, copper, zinc, argentiferous lead, quicksilver, and other ores, which are, to some extent, treated in the country, but are, for the most part, exported. These deposits usually occur either as lodes traversing the older rocks, or in lenticular masses interstratified with their bedding. Lead occurs in combination with sulphur as galena, while zinc, principally as carbonate or silicate, is found in the Silurian rocks of Sardinia, and also to a small extent in the Triassic dolomites of Lombardy. Copper occurs in the older slates as copper pyrites, either in beds of various thickness as at Agordo in the Aosta Valley, in veins in the serpentines and gabbros of Tuscany and Liguria, and, lastly, in quartz veins traversing some of the older rocks of Tuscany. Quicksilver is obtained from deposits of cinnabar occurring in the Eocene rocks of the Monte Amiata. Iron ores occur in various localities in the Aosta Valley and in other places. In the Alps there are deposits of magnetite, which, although somewhat difficult to treat, yield an exceedingly soft iron. There are also extensive deposits of spathic iron ore in the Triassic sandstones of Lombardy, which, for the most part, yield ores rich in manganese, and, when smelted with charcoal, afford iron and steel of good quality. Brown iron ores occur in irregular veins and masses at Gualdo Tadino in the Central Apennines, and in the Atina Mountains. A limonite bed at Pazzano, in Calabria, somewhat extensively wrought by the ancients, was formerly worked by the State, and afterwards by private individuals, but was ultimately abandoned as unprofitable.

The most important iron mines are those belonging to the Government in the Island of Elba, where the ore consists chiefly of hæmatite and magnetite deposited in irregular masses along the eastern coast of the island, where the proximity of the sea affords great facilities for shipping. The Kingdom of Italy is officially divided into ten mining districts, with a central office at Rome. The head-quarters of the ten districts are severally situated at Ancona, Caltanissetta (for the whole of Sicily), Florence, Genoa, Iglesias (for Sardinia), Milan, Naples, Rome, Turin, and Vicenza.[1]

Gold.—A considerable number of localities in Italy were known to the ancients as producing gold, but the only mines now of any importance are those situated in the mineral district of Turin in North Piedmont, where veins of quartz containing auriferous pyrites are enclosed in non-fossiliferous slates and schists. The mines of this district were extensively worked in the time of Pliny, who states that the Senate limited the number of slaves to 5,000 in order to prevent a reduction in the price of the precious metal. The principal amalgamation works are situated on various streams near the foot of Monte Rosa, a considerable amount of gold having been found in the valleys of Anzasca, Toppa, and Antrona. The most important mines are those of Pestarena and Val Toppa, worked by an English company, where the ore consists of quartz carrying granular auriferous pyrites. The rich portions of the vein run in well-marked chutes, nearly vertical, which though of no great length appear to continue down well in depth.

The production of gold during the year 1881 exceeded that of the previous year by 973 oz. 5 dwt. 23 gr., and the amount realised exceeded that obtained the previous year by £1,985 15*s.* 1*d.*

The returns for 1881 were as follows :—

	oz.	dwt.	gr.		£	*s.*	*d.*
From Pestarena	5,084	0	0	value	17,522	6	5
From Val Toppa	2,165	13	7	"	8,039	19	10
	7,249	13	7		25,562	6	3

At Pestarena the average yield of bar gold per ton of ore treated was 1 oz. 3 dwt. 11 gr., being 83·3 per cent. of the total amount present. At Val Toppa the yield of bar gold per ton was 6 dwt. 10 gr.; or 81·9 per cent. of the gold present was extracted.[2]

[1] The corps of Italian mining engineers, published about 1881, at the request of the Minister of Agriculture and Commerce, a collection of interesting statistics relating to the mining industry of Italy, entitled *Notizie statistiche sulla Industria Mineraria in Italia dal* 1860 *al* 1880, Rome, 1881, a volume of more than 400 pages. This has been republished in the *Revue Universelle des Mines*, and has also been translated by C. v. Ernst, who has materially added to it from his personal notes, and by extracts from *I Tesori sotterranei dell' Italia*, by G. Jervis, 3 vols. Turin, 1873, 1881. These papers appeared in the *Oesterreichische Zeitschrift*, and have been separately published, in book form, under the title of *Die Montanindustrie Italiens*, by C. v. Ernst, Vienna, 1883. More recently, an excellent annual report known as the *Rivista del Servizio Minerario* has been regularly issued by the Corpo Reale delle Miniere.

[2] *Report of the Pestarena United Gold Mining Company*, December, 1881.

More recently a number of other concessions have been acquired by this company; the chief source of the gold supply is still the Peschiera mine at Pestarena, but Val Toppa and Cani also produce some gold quartz. In the newer mines, Kint, Pozzone and Stabioli, work is chiefly confined to prospecting operations. During recent years[1] the results have been as follows:—

Period.	Quartz crushed.	Bar Gold obtained.	
		Weight.	Value.
	Statute Tons.	Ounces.	£
July, 1893—June, 1894 . .	5,788	7,527	27,285
July, 1894—Sept., 1895 . .	6,851	9,560	32,782
Total for 27 months . .	12,639	17,087	60,067

Almost the whole of the above quartz came from the Pestarena district; this yielded at the rate of 1 oz. 0 dwt. 7 gr. of fine gold to the ton of stone, or 86·8 per cent. of the assay value, during 1893-94, and 1 oz. 0 dwt. 22 gr. to the ton, equal to 88 per cent. of the assay value, during 1894-95. In the former period 451 tons of ore from the Val Toppa district yielded at the rate of 11 dwt. 3 gr. of fine gold to the ton.

According to Jervis[2] there were, in 1879, twenty-eight gold mines in Italy, producing in the aggregate 9,700 tonnes of auriferous ore. In 1880 the output of the Italian gold mines had increased to 11,709 tonnes of ore, worth £23,699; as, however, the Pestarena United Mines produced in that year gold to the value of £23,580 10*s.* 10*d.* it leaves only £118 9*s.* 2*d.* as the value of the gold obtained in all the other mines in Italy. In the various valleys running down from Monte Rosa, such as those of Antrona, Anzasca, Sesia, &c., there are numerous mineral-bearing veins, either in the gneiss of Monte Rosa, or in the zone of contact between the gneiss and dioritic schists.[3] A company known as the Monte Rosa Gold Mining Company, Limited, has commenced mining operations by drifting upon a well characterised quartz vein encased in gneiss.

In 1894 dredging operations were commenced for the treatment of the sands of the river Ticino. The plant was not quite in

[1] *Reports of the Pestarena United Gold Mining Company, Limited*, for 1894 and 1895.

[2] G. Jervis, *Dell' Oro in Natura*, Turin, 1881, p. 68.

[3] *Rivista del Servizio Minerario nel* 1894, p. 271.

thorough working order, nevertheless 1,100 cubic metres of sand were excavated and 485 grammes of gold were obtained (about 5¼ grains to the cubic yard). Operations are to be resumed in 1895, when it will be seen whether this industry is likely or not to prove an enduring one.[1]

Silver.—The first silver ores were discovered in 1870 at the Monte Narba Mine, on the eastern coast of Sardinia,[2] where the metal occurs in the native state, as sulphide, and sometimes as horn silver, or as pyrargyrite. Silver is now obtained from the mines of Monte Narba, Giovanni Bonu, Bacu Arrodas, and Correboi, in the east, and from Perda San Oliu, in the west, of the island, in the neighbourhood of Sarrabus. At Monte Narba the lode, about a metre wide, occurs in Silurian clay slate in the vicinity of porphyry, courses from east to west, and dips 70° north, parallel to the stratification of the country schists and of certain beds of quartzite, which the vein follows pretty closely. At Giovanni Bonu some remarkable masses of ore have been met with. The gangue consists of quartz, calc spar, and fluor spar, associated with clays and various silicates; heavy spar is rare, and the lode contains argentiferous galena as well as true silver ores, the argentiferous galena appearing to replace the silver ore in increasing proportion as greater depths are attained. At Sarcilone a French company is working on a cross fissure, running north and south, which proved extremely rich at one time, although barren at the outcrop.[3]

In 1881, 771,600 oz. of silver were obtained from the Sardinian silver mines. Their most productive year was 1885, when the value of the output was £96,000. In 1894 their production was 1,102 tonnes of silver ore, worth £31,770.

Quicksilver.[4]—At Vallalta, in the Agordino, a pyritic deposit is worked which contains cinnabar; the mineral is poor, yielding only ½ per cent. of quicksilver, and the mines ceased working in 1880. Cinnabar also occurs at Stazzema.

The principal centre, and now practically the only one in Italy, of mercury production is at Monte Amiata in Tuscany, where mining operations commenced about 1846. Monte Amiata is an eruptive mass of trachyte, breaking through strata of Eocene limestone; deposits of cinnabar are found in the zone of contact of the eruptive and stratified rocks, and also in bunches and small

[1] *Rivista del Servizio Minerario nel* 1894, p. 272.

[2] C. v. Ernst, "Silbererzvorkommen in Sardinien," *Oesterr. Zeitschr.* 1876, No. 9, and 1877, No. 7.

[3] Fuchs and De Launay, *Traité des gîtes minéraux et métallifères*, ii. p. 775.

[4] *Rev. Univ.* xi. 1882, p. 437.

irregular veins in formations of ages ranging from Miocene to Jurassic. The deposits occur principally in the calcareous strata, but are not quite confined to them. Owing chiefly to the irregular nature of the deposits, the various mines are worked on a small scale and somewhat erratically. The ore is found much intermingled with clay and associated with iron pyrites. Hepatic mineral springs and blowers of sulphuretted hydrogen gas occur within the mineral area apparently connected with the trachytic eruptives. The chief mines are those of Siele, which is the most important, Cornacchino, and Montebuono. The production of metallic mercury in this district for the last five years has been :—[1]

1890	449 tonnes
1891	330 „
1892	325 „
1893	273 „
1894	258 „

To obtain this last-named amount, 15,022 tonnes of low grade cinnabar ore were treated.

LEAD.—The most important lead mines of Italy are in the island of Sardinia, but there are also numerous deposits of lead ore on the mainland, although they have, in very rare cases only, given rise to mining operations upon an extensive scale. In the mining district of Turin the production of lead ore was in the year 1880 confined to the Tenda Mine, in the province of Cuneo. The ore produced is a finely granular galena, associated with copper pyrites, iron pyrites, and blende. It contains about 70 per cent. of lead with a little silver; its production in 1880 was fifty-six tonnes of ore, worth £440.

The district of Turin produced 100 tonnes of lead ore valued at £50 in 1894. Out of this quantity the Cuneo district produced 40 tonnes of poor ore. The Tenda Mine closed down in 1888; in 1892 the Vieille Montagne Company took over the mine and prospected it, but the result of their operations was the discovery of only some 2,000 tonnes of blende containing a certain amount of silver. As this quantity did not seem to justify the erection of the necessary tramways and plant, the mine was again abandoned at the end of 1894.[2]

In the mining district of Milan, the Brusimpiano Mine was

[1] *Rivista del Servizio Minerario nel* 1894, p. 110.

[2] *Ibid.* p. 271.

worked on a vein from three to six feet in thickness containing galena, cerussite, iron pyrites, jamesonite, copper pyrites and malachite. The Morso Alto is a lead mine, worked upon a lode twenty inches in thickness in syenite, filled with quartz and heavy spar. The galena contains 70 per cent. of lead, and is rich in silver. These mines, together with the Sotto Cavallo Mine and Casa della Miniere Mine in the province of Como, with the Lanzani Mine then recently opened near Bergamo, produced, in 1880, only 684 tonnes of ore, worth £3,566.

Practically the only mines in operation in this district in 1894[1] were those worked by the Brescia Mining and Metallurgical Company Limited, in Brescia. They are exploiting a network of veins that traverse a series of micaceous quartzites and schists of Carboniferous age; there are also a number of porphyry dykes intersecting these stratified rocks in the neighbourhood of the veins. These latter may be divided into three groups, the first striking N. 40° W., a second almost at right angles to the first, and a third intermediate in bearing between the two others. The veins are of very variable width up to two metres in thickness and carry galena, zinc blende and spathic ore. The output[2] for 1894 was 1,670 tonnes of lead ore and 2,790 tonnes of zinc ore. In that year the entire district of Milan produced 1,750 tonnes of lead ore, valued at £7,090.

In the mining district of Florence, the Bottino Mine is the only one which deserves mention, on account of the occurrence of argentiferous galena. In this mine, which was probably worked by the Etruscans and Romans, the lode courses from north-west to south-east with a dip of 55° south-west, and consists partly of finely granular, partly of coarsely crystalline galena, all varieties of which are equally rich in silver. Fahlerz, bournonite, and native antimony are, to a small extent, mixed with the galena, and the geodes sometimes contain crystals of rare beauty. The gangue is quartz mixed with slate. The country rock is gneiss, mica schist, or talc schist, of Palæozoic age. In 1880 the production was 661 tonnes, worth £2,355, but it has been closed down since then, and in 1894 there were no lead mines at all at work in this district. No other lead mines on the Italian mainland are worthy of particular notice, since the production of lead ores in the Vicenza district was for 1880 only 11 tonnes, worth £115; it was only 70 tonnes, worth about £90, in 1894.

[1] *Rivista del Servizio Minerario nel* 1894, p. 205.

[2] *Ibid.* p. 185.

The importance of Sardinia[1] as a lead-producing region is evident from the fact that out of the sixty lead mines working in Italy in the year 1880, fifty-four were in that island.

The lead mines of Sardinia may be divided into three types:

1. Ore masses interstratified in Silurian rocks, as at the celebrated mine of Monteponi.

2. Veins traversing Silurian clay slates, as at Montevecchio.

3. Lodes traversing the Silurian limestones, Malacalzetta, near Iglesias, representing this form of occurrence.

The Montevecchio, which is amongst the most important lead veins of Europe, is worked on a wide quartzose lode, and upon several leaders of less importance. The former, which is called the Great Lead Lode of Montevecchio, traverses the Silurian slate, almost parallel to its contact with the granite for a distance of 600 fathoms, and its outcrop may be traced in a straight line for a distance of nearly six miles from east to west, when it bends to the south-west; it dips 70° north. The ore consists of galena mixed with blende, iron pyrites, heavy spar, siderite and copper pyrites. The thickness of this great lode varies from 75 to 100 feet. The Ingurtosu and Gennamari Mines are also worked on the same lode. At the Marganei Reigraxius Mine there are two lodes, one in Silurian limestone with a quartzose gangue and much calc spar; the other a contact lode between limestone and Silurian slate. The strike of the strata is north-north-west, and the dip south-south-west. The quartz lode courses from east to west and dips south. The upper portion was worked by the Romans, as lamps, tools, &c., have been found down to a depth of thirty-six fathoms. The strike of the contact lode is north-north-west with a dip north-north-east. The ore in this lode is poor in silver, while the quartz lode yields ore containing 70 per cent. of lead, and from 55 to 60 oz. of silver per tonne. In the Montevecchio[2] concessions, there were extracted during the year 1894 a total of 20,634 cubic metres of vein-stuff, which yielded on dressing 8,624 tonnes of galena containing 70 per cent. of lead and 0·0564 per cent. of silver, and 1,196 tonnes of blende containing 50 per cent. of zinc. In the same year the neighbouring mine of Piccalinna produced 877 tonnes of galena containing 71 per cent. of lead and 0·09 per cent. of silver.

[1] *Oesterr. Zeitschr.* 1872, p. 3. "Relazione del Deputato Sella alla Commissione d'inchiesta sulle condizione dell' industria mineraria nell' Isola di Sardegna, 1871," *Berg. und Hüttenm. Zeit.* 1879, p. 165.

[2] *Rivista del Servizio Minerario nel* 1894, p. 154.

The lode at Malacalzetta is enclosed in Silurian limestone, and varies in width from eighteen inches to seven feet six inches; its course is east and west, and its dip 60° south. The veinstone consists of quartz and calcite with a little clay; the ore usually contains 74 per cent. of lead, and carries 40 oz. of silver per tonne. The depth of the main shaft is about ninety fathoms. It has been steadily worked for many years, and was still working, though not very productive, in 1894.

Since the year 1840, Monteponi has been one of the most important mines in Italy. The galena here occurs neither in lodes nor in regular beds, but in gigantic isolated columns of several hundred yards in height, which may be followed from north 15° west to south 15° east for a distance of 100 fathoms. Fifty-seven of these columns have been worked; they mostly occur at the contact of clayey limestone with dolomite. In addition to galena and other metallic sulphides, these columns are filled with calc spar and clay. The total length of the galleries in this mine is about twenty-seven miles. In 1838 this was the only lead mine in Sardinia. From 1832 to 1848 only 300 tonnes of lead ore were produced here per annum, in 1861 the production had increased to 6,382 tonnes, and in 1875 it reached 10,453 tonnes. The ore contains 70 per cent. of lead, and from 5 to 9 oz. of silver per tonne. In 1894,[1] raw ore to the amount of 101,227 tonnes, the output of Monteponi, was treated, producing 2,068 tonnes of galena yielding 64 per cent. of lead, and 9,030 tonnes of calcined calamine yielding 47 per cent. of zinc.

In the year 1860, twelve lead mines only were working in the whole of Sardinia, employing 3,425 miners, and producing 9,165 tonnes of ore. In 1870, 5,047 miners were employed, and 25,000 tonnes of ore were produced. In 1880, 36,143 tonnes of lead ore were produced in Sardinia, worth £357,376. In 1894, the production was 27,725 tonnes of lead ore, worth £134,080.[2]

Zinc.—Zinc ores usually occur in Italy in association with those of lead, and this is particularly the case in the island of Sardinia. On the mainland the mines of the Valle Seriana and of the Valle Brembana, in Lombardy, may be mentioned, but three mines only on the Italian continent were returned in 1880 as productive of zinc ores.

Parré, in Bergamo, has been worked for calamine containing 40 per cent. of zinc. Costagels, near the latter mine, was more

[1] *Rivista del Servizio Minerario nel* 1894, p. 158.
[2] *Ibid.* p. 142.

recently opened. At Argentiera, near Auronzo, in the district of Vicenza, on the Tyrolean frontier, zinc occurs in irregular deposits in Lower Triassic slate, and in dolomitic limestones belonging to the Middle Trias. Up to the year 1868, the Argentiera Mine appears in the official returns with an average annual production of only 200 tonnes. In 1869 the two other mines are noticed; their production began with 120 tonnes and increased year after year until, in 1879, their yield was 8,000 tonnes. The Argentiera Mine produced in 1894[1] about 22,000 tonnes of raw ores, which yielded on dressing 2,208 tonnes of calamine and 70 tonnes of galena. It was practically the only mine in the district that produced any zinc ore during that year.

During 1894, the province of Bergamo, district of Milan,[2] was by far the most important zinc-producing area of the Italian mainland. The Costagels and Gremme Mine still takes the lead in the Valle Seriana, and alone produced nearly one-half of the zinc ore of the entire district. Like several other mines in the district it is owned by the English Crown Spelter Company, Limited; the Vieille Montagne and the Austro-Belge Companies also hold important concessions in this province. In Valle Brembana the Monte Arera Mine is the most important. In several mines in the valley of the Riso, as also in the Casa Conti and others, a good deal of zinc is got by open-cast working. The entire district of Milan, *i.e.*, Lombardy, produced in 1894, 19,280 tonnes of zinc ore, worth £25,830.[3]

The deposits of zinc ore worked in Sardinia by the Malfidano Company are of two kinds, but, for the most part, they partake of the character of bedded veins; this is the case at Malfidano, Genna-Arenas and Planu-Sartu. Sometimes, however, they occur as chimneys of ore bearing no apparent relation to the stratification of the enclosing limestone, excepting that they preserve the same dip, which is nearly perpendicular, as at Planeddu and Monte Reggio. The enclosing limestones are supposed to be of Silurian age. The most important of these deposits is that of Malfidano, discovered in 1865, which contains calamine, blende, galena, and cerussite, which are irregularly mingled, without any recognisable order of succession; calamine, however, predominates to such an extent as to constitute seven-eighths of the whole. The deposit of Malfidano takes the form of an immense bedded vein parallel to the stratification of the limestone, but its limits have not,

[1] *Rivista del Servizio Minerario nel* 1894, p. 294.
[2] *Ibid.* p. 201.
[3] *Ibid.* p. 185.

as yet, been accurately determined. This deposit appears to have two branches, in the more important of which the calamine is generally distributed in chimneys, which are parallel to the bedding of the limestone. These chimneys, which vary considerably in their horizontal dimensions, have sometimes a thickness of sixty feet. When several of these unite, which is not unfrequently the case, the ore sometimes extends in the direction of its strike for a distance exceeding fifty fathoms. In other cases the calamine is distributed in branches of varying thickness, but, in both instances, the distribution of the ore follows the dip of the strata. It is on this branch of the deposit that the mine of Malfidano, properly so-called, is situated, as the other contains but few workable deposits.

At Planeddu the deposit has the form of an inverted truncated cone, the larger base reaching the surface, where it presents an area of about 1,400 square yards; thirty fathoms from the surface, however, the area becomes reduced to 132 square yards, and below that depth there is no mineral of any importance. The ore, which appears to be to a large extent worked out, is principally earthy calamine carrying from 39 to 42 per cent. of zinc.

At Monte Rexio various irregular masses of calamine occur in dolomitic limestone, and of these the mass bearing the name of "De la Route" is the most important. It measures 50 fathoms in length by 15 fathoms in width, and has been worked to a depth of 25 fathoms without reaching its inferior limit. The ore, for the most part, consists of white calamine, which is nearly pure carbonate, and of yellowish calamine, covered with crystals of silicate of zinc. With these are associated calcite and a ferruginous gossan containing a small proportion of zinc. The ores obtained from this mine are rarely or never associated with metallic sulphides. In the Genna-Arenas Mine, to the west of Monte Rexio, the deposit consists of lenticular masses, either isolated or connected by branches of calamine.

The Planu-Sartu concession contains two separate deposits, known as the north and south ore bodies. With the exception of Malfidano, the south body is the most important as well as the most regular deposit belonging to the company. Its general strike is north 25° east, and its outcrop can be traced for a distance of 185 fathoms, and is from 20 to 25 fathoms in width. At the surface the ore forms a series of lenticular masses, arranged like a string of beads parallel to the bedding of the enclosing limestone. In depth the walls of these ore bodies approached each other in such a way that it was at one time feared they were about to give out. Subsequent explorations, however, showed that at still greater depths there are vein-like masses of considerable thickness, and of greater regularity than are usually found in deposits of calamine. Five of these, varying from 4½ to 15 feet in width, have been met with, and have been remarkable for their continuity in depth; at some points they opened out to a width of nearly forty feet. The colour of the ore varies from white to nearly black, and the texture is as variable as the colour. The north body, which is parallel and analogous to the south, is comparatively unproductive.

The following statistics relative to the production of zinc ores in the island of Sardinia, will serve to indicate the progress of this industry since its commencement in 1865:—[1]

Year.	No. of Mines.	Tonnes of Ore produced.	No. of Miners employed.
1865	1	449	35
1870	3	92,000	2,192
1875	13	58,165	2,315
1879	24	63,039	2,713
1880	—	67,551	—
1885	—	100,000	—
1890	77 [2]	99,400	9,622 [2]
1894	65 [2]	110,241	8,464 [2]

COPPER.—In the Aosta Valley, mining district of Turin, are situated the copper mines of San Marcello, Champ de Praz, and Ollomont. The latter, which is of especial importance, was opened at the beginning of the last century, the ore being a cupriferous iron pyrites containing, on an average, 3 per cent. of copper. The deposit occurs in chloritic schist associated with granite, and is conformably stratified, its course being north-west, with a dip of 40° towards the south-west: the gangue consists of quartz, hornblende, chlorite, talc, and calc spar.

B. Lotti[3] has published an account of these deposits, which are, according to him, connected with certain eruptive rocks. The Eocene schists of the district are traversed by serpentine (Lherzo-

[1] *Notizie Statistiche sulla Industria Mineraria in Italia dal* 1860 *al* 1880, Rome, 1881. *Rivista del Servizio Minerario.*

[2] Including lead mines.

[3] *Zeitschr. f. Prakt. Geol.* 1894, p. 18.

lite), gabbro and diabase in this order, the last-named being the youngest. The ores, consisting of iron pyrites, chalcopyrite, erubescite and copper glance, occur in irregular deposits at the contact of the gabbro with the other rocks, at times disseminated through it, at times in small threads or veinlets and at times in nodular masses, varying from a few inches to some four feet in diameter, in a steatite-like rock, a decomposition product of the gabbro. The ores are practically confined to the gabbro, from which they have, according to Lotti, segregated by a process of differentiation and concentration from the eruptive magma.

He ascribes a similar mode of formation to the deposits of copper ore in serpentine in Liguria.

The other copper ore deposits in the Alps are of no special importance. Three mines were working in this district in 1880, the production during that year being 2,404 tonnes of copper ore, worth £6,696. This district has greatly fallen off since then, and in 1894, three mines at work produced 257 tonnes, worth about £150.[1]

In Liguria, mining district of Genoa (Carrara), the mines of Monte Loreto, Le Cascine, and Libiola, may be mentioned as fairly productive. These are worked on copper pyrites and cupriferous iron pyrites, occurring in veins of quartz and calc spar, enclosed in serpentine and diorite. The Loreto Mine was opened in 1857, and old Roman workings, of which there is no record, were then discovered. Le Cascine is worked by an English company. Libolia has been worked since 1866. In 1874 a depth of about seventy fathoms had been attained, and the adits and levels had then a total length of 2,187 fathoms. The ore, which contains from 7 to 12 per cent. of copper, goes to Swansea.

The total production of the three copper mines in the mining district of Genoa was, in 1880, 5,662 tonnes, worth £17,095. In 1894 there were only two mines in operation; Libiola, by far the most important, produced over 12,000 tonnes of copper ore with about 10 per cent. of metal, and 6,350 tonnes of iron pyrites. The other mine, Gallinaria, was only worked to a very limited extent. The output of the entire district for 1894[2] was 12,450 tonnes of copper ore, valued at £26,520.

In the mining district of Vicenza, in the Cordevole Valley,

[1] *Rivista del Servizio Minerario nel* 1894, p. 260.
[2] *Ibid.* p. 72.

is the ancient mine of Agordo,[1] worked on a thick deposit of cupriferous iron pyrites, containing a little galena and blende. The ore is enclosed in a clay slate, which becomes very quartzose near its junction with limestone or sandstone. This deposit has been followed for a length of 300 fathoms in the direction of its strike, and for above 100 fathoms on its dip. The average thickness of the mass is about sixty feet, and the ore contains 1·80 Cu, 3 Zn, 39 Fe, 50 S, 1·4 As, and SiO_2 5 per cent. This mine belongs to the Italian Government. B. v. Cotta describes the form of the deposit at Agordo as that of a "flattened sausage," and compares the light slate surrounding it with the *Skölar* of Fahlun. A. v. Groddeck classes it with his "Pyrites bed type," which includes Fahlun, Ducktown in Tennessee, Schmöllnitz, Rammelsberg, Rio Tinto, and Tharsis.

The production of Agordo was for a time as follows :—

	Tonnes.		Tonnes.
1875	14,954	1878	11,498
1876	12,291	1879	11,039
1877	12,622	1880	14,872

The value of the production of the year 1880 was £5,719. The mine has since been abandoned. A similar deposit is now being worked chiefly by open-cast in the same district at Vallimperina. Its production in 1894, nearly twice that of 1893, was 13,843 tonnes of cupriferous pyrites.[2]

The copper ore deposits of the Tuscan Apennines, mining district of Florence, have given rise to various important mines. Between Genoa and the sources of the Tiber and Metaura, numerous masses of eruptive rock burst through Cretaceous and Tertiary beds on both sides of the Apennines. The latter rest conformably upon the former, but they are difficult to distinguish petrographically, although separated by the Nummulitic horizon. The eruptive rocks are gabbros and serpentines, and in the vicinity of the junction of these rocks with the sedimentary formations occurs the so-called "*Gabbro rosso*" which is weathered red by the peroxidation of iron. J. Cocchi distinguishes, in addition to the older eruptive rocks associated with the serpentines and belonging to them, always marked by the presence of diallage, a more recent

[1] B. v. Cotta, *Berg. und Hüttenm. Zeit.* 1862, p. 425. Bauer, *Oesterr. Zeitschr.* 1863, p. 101. B. Walter, *Oesterr. Zeitschr.* 1863, p. 114. A. St. Schmidt, *Berg. und Hüttenm. Zeit.* 1867, p. 243. See also v. Groddeck's paper on "Sericite Rocks," quoted on p. 367.

[2] *Rivista del Servizio Minerario nel* 1894, p. 293.

serpentine enclosing no diallage, which traverses the older rocks in the form of veins. This serpentine frequently contains deposits of sulphuretted ores, especially those of copper.

The most important copper vein yet discovered is that of Monte Catini,[1] which occurs in *Gabbro rosso*, or melaphyre according to G. v. Rath, who is of opinion that the serpentine was originally a cupriferous olivine, and that, on its conversion into serpentine, dislocations and contortions in the bedding took place. The lode is enclosed in a very brittle red gabbro, and is filled with broken fragments of that rock, together with pieces of diorite, euphotide, ophiolite, and serpentine. It comes from east to west, at first with a dip of 45° north; but later, at a depth of sixty fathoms, it turns over to the south, and at this point the vein is above ninety feet in thickness. The pure ore contains Cu 32·79, Fe 29·75, S 36·15, Gangue 0·86 per cent. and averages from 20 to 30 per cent. of copper; native copper also frequently occurs.

This lode was worked by the Etruscans; but under the Romans mining was less actively carried on, as the Tuscan mines could not compete with the richer workings of Spain and Cyprus. Monte Catini was also worked during the early middle ages, but was brought to a standstill by the plague in 1630, and the workings were not subsequently resumed for more than a century. The third epoch of the prosperity of this mine is of comparatively recent date.

The Etruscans, with their narrow shafts and contracted levels, penetrated only into the uppermost rich horizon; in the middle ages the workings were deeper; while recently they have reached a depth of 170 fathoms. In the year 1845, 900 tonnes of ore were produced, containing 30 per cent. of copper, and in 1850 the production reached 3,000 tonnes. Many horizons were then wrought at the same time, and several of the richest were worked out, while corresponding riches were not met with in depth. In this way the production quickly became reduced, and in 1870 the mine was stopped in consequence of a lawsuit. Since that period, however, under the direction of M. A. Schneider, the annual production again reached from 1,000 to 1,200 tonnes. According to Reyer,[2] the eruptive rock-mass with which the ore is associated is surrounded by more recent marls, and consists principally of red gabbro, which in places becomes green and resembles serpentine; the miner, he states, er-

[1] G. v. Rath, *Zeitschr. d. d. geol. Gesellsch.* xvii. 1865, p. 282. A. v. Groddeck, *Die Lehre von den Lagerstätten der Erze*, Leipsig, 1879, p. 150.

[2] E. Reyer, *Berg. und Hüttenm. Zeit.* 1882, p. 325.

roneously calls the green eruptive masses "serpentine," and the red "gabbro." On the south flank of this igneous mass, between the eruptive rock and the marls, the famous copper deposit occurs; it

FIG. 94.—Monte Catini; transverse section.

courses east and west for a distance of about 300 fathoms, and is rich in ore so long as it traverses the eruptive mass.

The engine shaft is 172 fathoms in depth, passing through the eruptive rock, the ore deposit, and lastly into the older marl. The

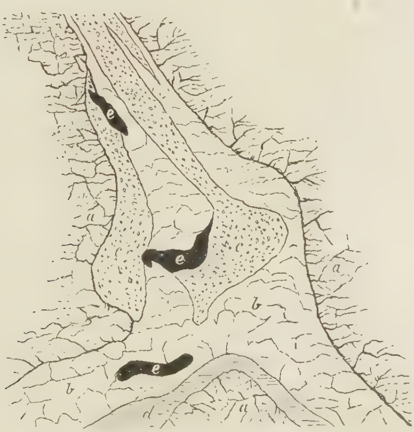


FIG. 95.—Monte Catini; transverse section.

main adit is about 1,100 fathoms in length, and the lode, which is large, varies considerably in thickness.

Figs. 94 and 95, after A. v. Groddeck, represent two vertical sections of the Monte Catini copper deposit in which *a* is melaphyre, *b* serpentine, *c* conglomerate of melaphyre and serpentine, *d* limestone and marl, and *e* masses of copper ore.

The Capanne Vecchie copper mine also appears to have been worked by the Etruscans, but was first re-opened in 1846. The ore is copper pyrites occurring in amphibolite as country rock; the lode courses from north to south and dips east. The ore usually contains Cu 18·01, Fe 43·33, and S 30·35 per cent., with traces of gold. Several other copper mines are working in Tuscany, but they are all of subordinate importance. The total production of the Tuscan copper mines in 1880 was 9,361 tonnes of ore, worth £40,673. In 1894 it was 66,335 tonnes, worth £52,980.[1] In 1879 thirteen copper mines were at work in Italy, employing 1,366 miners, and producing 20,751 tonnes of ore. In 1894[2] there were sixteen mines, employing 2,003 miners, and producing 92,886 tonnes of ore, worth £83,550. Of this ore, 7,789 tonnes,[3] containing 779 of metal, were exported, and the remainder, treated in the kingdom, yielded about 9,000 tonnes of metal.

Tin.[4]—Early in the year 1875, during the prosecution of some excavations for hæmatite in the vicinity of Campiglia Marittima, masses of a heavy material attracted the attention of the foreman in charge of the work, who, on account of its uncommon weight, put aside a piece of the stone. Some fragments of this mineral having come under the notice of M. Blanchard, a French mining engineer, he forwarded them to London, where they were found to consist of cassiterite associated with calcite and ferric oxide. Campiglia Marittima is a small town situated about four English miles from the Tuscan coast, and thirty-five miles south-east of Leghorn. It was in one of the excavations, made either by the Etruscans or Romans, two miles south-east of Campiglia, that this discovery of cassiterite was made. This ancient mine, now known as the Cento Camerelle, consists of a number of small excavations connected by galleries cut out of hæmatite and limestone in the flanks of Monte Fumacchio. The infiltration of calcareous waters during twenty centuries had here deposited a stalagmitic crust, of from five to ten inches in thickness, on the walls, and it is not improbable that the mine was abandoned after the destruction of Populonia by Sylla. During the middle ages no mining was carried on, and in 1858, when M. Blanchard, accompanied by M. Simonin, visited the mine, they found it in-

[1] *Rivista del Servizio Minerario nel* 1894, p. 110.
[2] *Ibid.* p. xx. [3] *Ibid.* p. xxviii
[4] *Iron*, xiv. 1879, p. 166; E. Reyer, *Zinn.* 1882, p. 156.

habited by legions of bats, while on the floor had accumulated a deposit of guano, sufficient to form the object of an industrial enterprise. In 1872 M. Charlon commenced excavations for hæmatite, but in 1873 the property came into the hands of the present owners, and was worked for iron ore upon a considerable scale. A tin lode was discovered about forty-five feet west of the most extensive ancient workings. Its direction was at first nearly east and west, but it varied greatly both in size and strike, while the cassiterite was occasionally wholly replaced by hæmatite. The surrounding limestone is of Lower Liassic age, and as the excavations proceeded it was found that the cassiterite came from a horizontal bed of iron ore in which the Cento Camerelle had been excavated. On the outer borders of this, the tin ore made its appearance in irregular pockets, and in fissures in the limestone. It thus became evident that the workings might have been made for the extraction of cassiterite, and when they were at length reached, there were found, upon removing the concretions from the walls, more or less abundant traces of that mineral. In 1877 twenty-one tonnes of tin ore were obtained from this mine. Another mine on the east of the Monte Fumachio produced, in 1877, several tonnes of tin ore of an inferior quality. These mines produced, in 1878, 31 tonnes of tin ore, worth £384, in 1879, two tonnes, worth £16, and in 1880, 16 tonnes, worth £128. Up to 1894, some 70 tonnes in all had been produced, but none was obtained during that year.

ANTIMONY.—About nine-tenths of the Italian production comes from Sardinia, where numerous veins have been worked for a considerable period. In the district of Florence, at the mine Cetine di Cotorniano,[1] near Siena, there is a small hill of Permian rocks partly covered with Rhætic limestone in the midst of the Eocene formation, the Permian rocks being quartzose sandstones and schists. At the contact of the Permian schists with the Rhætic limestone there is a bedded deposit of chalcedonic quartz intermixed with stibnite; this deposit is clearly defined against its Permian foot wall, but passes gradually into the limestone of the hanging side. It is therefore probable that waters charged with silica and with antimony acted upon the limestone, forming this deposit metasomatically; the influence of the schists on the deposit is reduced to a blackening of the latter in the neighbourhood of the foot wall. The outcrop of the deposit along the line of contact has been followed for about 1,000 feet, with an east and west strike and a dip to the north of some 12°, the thickness of the deposit averaging

[1] *Rivista del Servizio Minerario nel* 1894, p. 127.

about forty feet. So far the deposit has not been sufficiently explored to enable its real shape or dimensions to be determined. The stibnite is very irregularly disseminated, the ore treated averaging about 5 per cent. The deposit presents numerous fissures running north and south, containing kermesite and valentinite, decomposition products of the original stibnite. In 1894 this mine produced 133 tonnes of liquated antimony, valued at £1,270.

Manganese.—Manganese ores occur principally in Liguria, Tuscany, and the island of San Pietro on the south-west coast of Sardinia. In the first-mentioned province they occur stratified in Tertiary rocks, while at San Pietro they are enclosed in trachytic tuffs. They are, for the most part, worked in a very primitive way, and have never given rise to mining upon an extensive scale. Some of the ores of Sardinia are only of importance on account of their high percentage of peroxide. Jervis gives a list of ten manganese mines working in Italy in 1881. The Praborna Mine, in the province of Turin, is worked for hausmannite, pyrolusite and manganite, the deposit being 24 feet in thickness and enclosed in a chloritic schist. At Cerchiera, in Genoa, the ore is amorphous, compact, of a violet black colour, mixed with some red hæmatite, and traversed by strings of calc spar, forming a bed twenty inches in thickness.

At Monte Argentario, in the province of Grosseto, a brown iron ore very rich in manganese occurs; it was extensively worked from 1874 to 1879, and the workings were resumed at the close of that year. The richer ore contains from 30 to 39 per cent. of manganese, and from 4 to 11 per cent. of iron; the poorer kind contains from 30 to 35 per cent. of iron, and about 18 per cent. of manganese. It is chiefly sent to England for making ferro-manganese. The production in 1894 was 5,810 tonnes, valued at £1,740.

At Capo Becco and Capo Rosso, in the island of San Pietro, there is a bed of pyrolusite twenty inches in thickness containing 60 per cent. of manganese. The ore is much in demand for chemical purposes. In addition to the above production of ferriferous manganese ores, Italy produced in 1894 ores of manganese of higher grade to the amount of 760 tonnes.

Iron.—Although rich in iron ores, which were worked even in pre-historic times, Italy, on account of the want of mineral fuel, does not produce a sufficient amount of iron to meet the requirements of the country. The most important iron-mining districts are situated in Piedmont, Lombardy, and the island of Elba.

Piedmont was formerly an important iron-producing country. Veins of magnetite occur in the Aosta Valley, at Cogne, and at

Traversella, which formerly gave rise not only to numerous iron mines but also to the erection of blast furnaces. The Licony Mine in the Cogne Valley is mentioned so long ago as the year 1300. This very extensive deposit varies from 66 to 98 feet in thickness, and consists, principally, of compact magnetite free from pyrites. The ore is of excellent quality and yields about 50 per cent. of iron, being interbedded between yellowish limestone and talc schist. The Larcinaz Mine lies north of the preceding, and has been opened on the continuation of the same deposit of magnetite. Spathic iron ore occurs in the vicinity of the limestone, and asbestos is found in both mines. The St. Oyen Mine, in the Great St. Bernard Valley, was worked by the Government from 1825 to 1831, but was then handed over to a private company. Both spathic iron ore and magnetite are obtained in this mine, and limonite occurs in the neighbourhood of the outcrop.

One of the most important iron ore deposits in Italy occurs in the Chiusella Valley. In 1835 there were at Traversella in this valley 80 iron mines, which produced 7,837 tonnes of ore, yielding 3,374 tonnes of cast iron. Ten years later the production had risen to 10,000 tonnes, but subsequently again declined to 1,400 tonnes. In 1880 only five mines were in operation. Crystalline magnetite with a granular structure, yielding from 40 to 50 per cent. of iron, forms the mass of the celebrated deposit of Traversella, which courses from north-west to south-east and has an almost perpendicular dip. The ore forms beds, or perhaps contact veins, in greenstone, and is accompanied by dolomite, calcite, quartz and chlorite. A rock, containing garnets and quartz, divides the main mass of the deposit into two parts. Copper pyrites, compact iron pyrites, galena, and a great number of other crystallised minerals, which are represented in all the principal mineral collections of Europe, have made this deposit universally famous.

In 1880 the mining district of Turin produced 1,813 tonnes of iron ore, representing a value of £880, and in 1894 only 1,000 tonnes, valued at £375.

Iron occurs in Lombardy as magnetite at Zebru and Saviore, as ochre in the older slates near Bormio, and lastly in the Triassic dolomites as spathic iron ore, the last only being of importance. This mineral occurs regularly stratified, in beds varying from a few inches to nine feet in thickness, in the lower Triassic sandstones as well as in the clay slates above them. Veins of this ore also occur beneath the Trias, but they are only of subordinate importance. The iron-ore zone extends from east to west for a distance of from nine to twelve miles into the mountains, and the annual production averaged about 25,000 tonnes in 1880. The most important mines are at Pisogne, in Valcamonica, in Val di Scalve, and in Val Trompia. In 1894[1] the most important mines were those of the Gaviera group, whose production nevertheless was only 900 tonnes, having fallen to this figure from 3,600 tonnes in 1891. The production of the entire district in the first-named year was only 12,099 tonnes[2] from 31 mines, or about one-half of what it had been five years previously.

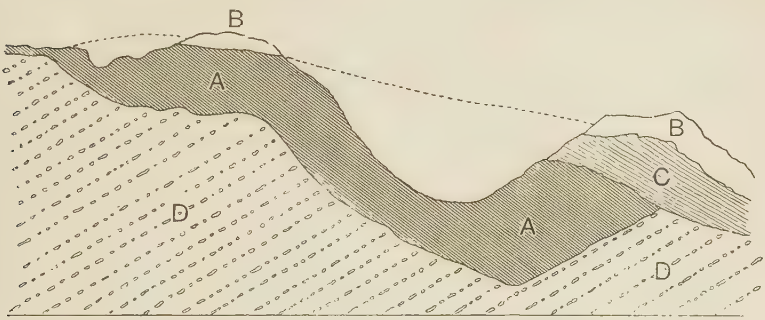
In Sardinia hæmatite occurs in the Silurian rocks of Acquaresi, Perdasterria, and Funtanaperda near Iglesias, and magnetite in Perda Niedda and San Leone, to the west of the Gulf of Cagliari. Of these only San Leone has attained any importance. The magnetite from this locality contains about 54 Fe, 1·12 SiO_2, 0·76 Al_2O_3, and 0·105 P per cent. The main lode courses from north to south and, in the west, closely approaches the granite, which assumes the character of syenite. Jervis is of opinion that the rock accompanying these magnetite lodes is contemporaneous with the greenstones of the Alps, and especially with the serpentines. Subordinate veins of magnetite traverse the main lode from north-north-west to south-south-east, and from north-north-east to south-south-west, while at the crossings rich ore deposits occur. The width of these sometimes reaches 26 feet. On the foot wall the gangue is quartzose; while on the hanging wall is magnetite varying from 26 to 33 feet in thickness, mostly mixed with garnets. The hanging wall consists of quartzose slate, which is separated from the lode by a distinct clay selvage. As long as the ore was worked by open-cast it yielded a profit, but when an adit had to be driven, the production, which was formerly considerable, sank in 1877 to 13,300 tonnes, while in 1879 and 1880 no returns were made.

The iron ores of Elba occur in veins and more or less irregular beds along the east coast of the island, and are worked at five different mines, namely: Rio Albano, Vigneria, Rio, Terranera, and Calamita. Of these Rio Albano, Vigneria and Rio, are the most important. The mineral consists of oxides of iron, chiefly hæmatite, limonite, red iron ore, and magnetic iron ore, with siderite; the gangue is quartzose, and iron pyrites is often present. The iron ore is found in beds from 60 to 100 feet in thickness. The rock is mostly siliceous slate, which in places is overlain by

[1] *Rivista del Servizio Minerario nel* 1894, p. 200.
[2] *Ibid.* p. 185.

limestone, the age of which has not been determined. The ore is obtained by open-cast workings, and more than 1,000 miners are employed.

According to Mr. H. Scott,[1] all the deposits are superficial, none of them having been proved in depth. Permian strata, chiefly quartzites and conglomerates, seem to form the floor upon which most of these deposits rest, and though very many different geological epochs are represented, most of the chief deposits seem to occur in Liassic strata. A characteristic section is shown in Fig. 96. At Cape Calamita the ore is associated with limestones



A. Iron ore. B. Ancient refuse. C. Upper Liassic schist. D. Permian conglomerate and quartzite
The dotted line shows the original contour.

FIG. 96.—Section of the Grattarina working; after H. Scott.

which enclose deposits of hæmatite. There are also here deposits of highly polar magnetic ore, the formation of which is possibly a subsequent action due to the action of eruptive masses of ilvaitic augite. Dr. B. Lotti[2] points out that the ores, though specially allied to the limestones, were also associated with the schists of the bed rock; he holds that the formation of these ore deposits took place in post-Eocene times, and ascribes to them a metasomatic origin. This is the opinion now most generally held, though some authors prefer to ascribe them to pneumatolytic action, considering that the iron was brought up as chloride in connection with the eruptive rocks of the island. This theory seems to have been originally formed to account for the well-known beautiful crystals of specular ore, which are however confined to a working known as Le Fabbriche, and is far from resting on a sound basis.

It is not known when mining operations commenced on this

[1] "The Mines of Elba," *Journ. Iron and Steel Inst.* 1895, I. p. 141.
[2] *Ibid.* p. 156.

island, but they certainly date from pre-historic times. According to Mr. Scott, they were worked for 3,000 years before 1750, during which time he estimates that ore was mined at the rate of about 4,000 tonnes per annum. During the next century it averaged 14,000 tons. From 1851 to 1881 it rose rapidly to an average of about 120,000 tons. In 1881 there were, however, 403,215 tonnes of ore mined, and the Italian Government, fearing the rapid exhaustion of the mine, thereupon restricted the output to 200,000 tonnes per annum. In 1884 the Government engineers made a careful examination, and reported that there were 8,000,000 tonnes available; the Government then restricted the annual production to 180,000 tonnes, at which figure it still remains.

The following table shows the production of the various mines in the years 1880 and 1894:—

Mines.	1880.	1894.
	Tonnes.	Tonnes.
Rio Albano	32,185	54,098
Vigneria	20,192	15,136
Rio	191,953	74,056
Terranera	17,909	2,817
Calamita	12,083	28,122
Total for Elba	274,322	174,229

SUMMARIES OF THE PRODUCTION OF METALLIFEROUS MINERALS IN ITALY DURING THE YEARS 1880 AND 1894.

1880.[1]

Description of Ore.	Quantities.	Values.	
	Tonnes.	Lire.	£
Iron ore	290,974	3,127,848	125,114
Zinc ore	76,089	4,397,816	175,912
Lead ore	37,555	9,096,197	363,848
Copper ore	32,299	1,754,819	70,192
Silver ore	1,802	2,229,159	89,166
Gold ore	11,709	592,479	23,699
Quicksilver, metallic	115,940 Kg.	579,700	23,188
Manganese ore	6,505 T.	214,390	8,575
Antimony ore	402	80,400	3,216
Iron pyrites	4,663	56,769	2,270
Tin ore	16	3,200	128
Total value of Metalliferous Minerals produced in 1880		22,132,777	885,308

[1] *Notizie Statistiche sulla Industria Mineraria in Italia dal* 1860 *al* 1880, p. 406, Rome, 1881.

1894.[1]

Description of Ore.	Quantities.	Values.[2]	
	Tonnes.	Lire.	£
Iron ore	187,728	2,089,156	78,343
Manganese ore	760	23,500	881
Ferriferous Manganese ore	5,810	46,480	1,743
Copper ore	92,886	2,228,146	83,555
Zinc ore	131,777	9,198,955	344,961
Lead ore	29,822	3,792,111	142,204
Silver ore	1,103	847,222	31,771
Gold ore	7,748	663,908	24,897
Antimony ore	1,504	225,295	8,449
Mercury ore	15,022	1,017,241	38,146
Iron pyrites	22,638	296,347	11,113
Total value of Metalliferous Mineral produced in 1894		20,428,361	766,063

GREECE.

But little is accurately known relative to the geology of Greece.[3] The lowest beds consist of crystalline schists and granular limestones, in which no vestige of either animal or vegetable life has been found. After careful examination, Cordella has arrived at the conclusion that the marbles of Paros and Laurium are entirely destitute of fossils. The siliceous limestones of the Peloponnesus, forming the base of the Secondary rocks, are without fossils, and it appears to have been assumed that these crystalline sedimentary formations likewise belong to that period, the fossils which they originally contained being supposed to have become affected by the action of agencies which eventually resulted in their disappearance. The greater portion of the Cyclades, Eubœa, and a large proportion of the continent of Greece consists of such rocks, which sometimes rise to an elevation of 6,500 feet above the sea level. Among these, crystalline mica schists predominate. The metalliferous mica schist of Laurium is composed, according to recent studies of M. Szabò, of a mixture of biotite and

[1] *Rivista del Servizio Minerario nel* 1894, p. xx.

[2] The lira is here taken at ninepence.

[3] A. Cordella, *La Grèce sous le rapport géologique et minéralogique*, Paris, 1878; *Ibid.* "Le Laurium," Marseilles, 1869; *Ibid.* "Mineralogisch-geologische Reiseskizzen aus Griechenland," *Berg. und Hüttenm. Zeit.* 1883, pp. 21, 35, 41, 57; *Ibid.* "Description des produits des Mines du Laurium à la troisième période Olympienne," Athens, 1875; *Ibid.* "Περὶ τῶν σκωριῶν καὶ τῆς Μεταλλουργικῆς Βιομηχανίας ἐν Ἑλλάδι," Athens, 1865.

andesine, and has a specific gravity of 2·60. M. Sauvage regards the phyllites of Mount Pentelicus as of Cretaceous age, and bases this opinion on the discovery of a fossil belemnite. Dr. Neumayer agrees with this hypothesis, having in 1873 found a Cretaceous fossil in the vicinity of the Acropolis. The numerous quarries of crystalline limestones near Laurium have not yet shown a single trace of any organism excepting a partially obliterated cast, found by Cordella, resembling a Silurian crinoid; there is consequently great difficulty in determining the age of these rocks.

The oldest known fossiliferous rocks probably belong to the Cretaceous age, and it hence appears that there must be in Greece a considerable gap in the geological succession. Silurian, Devonian, Carboniferous, Permian, Triassic, or Jurassic rocks have not been discovered. The Tertiary rocks of Greece, which are well represented, compose the northern portion of the Peloponnesus, and a large part of the mainland and of the Ionian Islands, as well as of many of the Cyclades. On account of their regularity and the number of well preserved fossils which they contain, they present a less difficult geological study than do the Secondary rocks. The most characteristic rocks of Greece are, however, of eruptive origin, principally trachytes. The plutonic rocks include granite, porphyry and serpentine. Among the volcanic series are such rocks as obsidian, perlite and pumice.

The mining industry of Greece, previously very limited in modern times, after being abandoned for 2,000 years began to be re-developed in 1861, the date of the promulgation of mining laws based on the French law of 1810. In 1864 a company was formed, Hilarion, Roux & Co., to work the ancient lead slags of Laurium; and in August, 1875, the *Société Française des Mines du Laurium* was established with a nominal capital of 13,500,000 francs.

Gold.—Gold is found in the sands of the rivers near the town of Skyros, and in the vicinity of the village of Doliana, in the Peloponnesus, there is a bed of iron pyrites containing a little gold. This metal also accompanies silver in argentiferous galena; but the known occurrences of gold alone are of no commercial importance.

Lead, Silver, and Zinc.—Ores of lead, silver, and zinc, are the principal mineral products of Greece, but as they constantly occur associated in the same deposit it becomes impossible to describe them separately. Silver has not as yet been found in the native state, but occurs in association with lead in variable proportions. In the lead from the Laurium mines the average percentage of silver is greater than in that from any of the other mines of Greece. In the latter the maximum may be taken at 0·25 per cent. (81½ oz. per ton), while at Laurium the maximum sometimes reaches 1 per cent. (326 oz. 13 dwt. 8 gr. per ton), and never falls below 0·1 per cent.

Argentiferous lead ores occur in mica schists, limestones, granites and trachytes, sometimes as irregular masses, and sometimes in the form of lodes. Calamine was discovered by Cordella at Laurium in 1870, and occurs both as masses and as independent veins in limestone, being sometimes mixed with argentiferous lead ore.

The principal mineral district is that of Laurium, at the southern extremity of Attica. The rock is chiefly a crystalline schist, in which are conformably interstratified subordinate beds or irregular lenticular masses of crystalline limestone. These strata have been broken through by granite, porphyry, and by more recent igneous rocks, to the influence of which the accumulation of metalliferous minerals is generally ascribed. The ferruginous, plumbiferous, and zinciferous deposits, which have followed these outbursts, have filled fissures and cavities in the limestone, and have also accumulated at the point of contact of the limestone with mica schist, thus forming irregular masses. In mica schist the ore generally occurs in the form of veins, but it is difficult to determine whether these were formed at the same time as the metalliferous enclosures, or whether they were subsequently produced. At Camaresa, the centre of the operations of the *Société des Mines du Laurium*, one of the beds has been proved to be metalliferous over an area of a mile and a half square, and the contact deposits vary from three to twenty-two feet in thickness, while parallel ore-bearing beds are found at various levels. Four of these were known to the ancients, and the existence of others below their deepest workings has been shown by recent investigations. The ores consist of galena, cerussite, blende and zinc carbonate, associated with sulphides and carbonates of copper, iron pyrites, and spathic iron ore. Generally speaking, the main portion of the ore bodies consists of galena more or less mixed with blende, while carbonate of zinc occurs partly on the walls and partly as separate deposits. A rare mineral, adamine, a zinc olivenite, appears to be characteristic of the ore deposits of this locality.

The mines of Laurium were worked by the ancients with great skill and perseverance, the ore having been reached by means of numerous vertical and inclined shafts. Adit levels were not employed, as not only was the topography of the country unfavourable to their construction, but the dryness of the mines also rendered them unnecessary. The working of the ancient mines was systematically conducted, the ore having been extracted from the veins by stoping from one level to another, and from the beds by pillar and stall. When the ore was comparatively pure, it was all removed and pillars of dry masonry were substituted, but when the galena was much mixed with blende, forming an intractable mixture for smelting, pillars of veinstone were left standing. In the thicker beds two floors were sometimes established, as is now the practice in working thick coal seams. The extraction of the ore was very complete, as even the metalliferous wall rock was invariably removed. Dry masonry appears to have been exclusively employed in the few cases in which the walls or roof needed support. The tools used were picks, bars, and sledges, but fire-setting does not appear to have been resorted to for disintegrating the rock, which is not well suited for the employment of that process. Traces of the use of tools are constantly met with, and an iron gad found by M. Cordella, although completely oxydised, still retained its shape.

The ore was carried up the inclined shafts, probably in skin sacks, and the water must have been got rid of in the same way. In the inclines, the steps up which the men went are still visible, as well as are numerous niches for lamps, many of which have been found in place. From the circumstance that heaps of vein-stuff, &c., surround the perpendicular shafts, M. Cordella is of opinion that the windlass and pulley were to some extent employed for hoisting. These shafts also served for ventilation, and at the top of some of them a sort of chimney has been found, in which a fire was probably built to increase the natural circulation of air. The deepest shaft mentioned was 395 feet in depth, but none of them reached the sea level. A portion of the ore removed from the mine at this early period was too poor to admit of being economically smelted, and was consequently subjected to a process of concentration. Some of the appliances used for this purpose have been found under the slag-heaps in a tolerable state of preservation.

Water was scarce at Laurium, and large reservoirs were built for the purpose of storing a sufficient supply; these were so strongly constructed that they might even now be employed for the purpose for which they were originally designed. The washing apparatus was so planned as to admit of the water being used over again continuously, and consisted of a sluice, some seventy feet long, provided in its length, at intervals, with small reservoirs or wells.

Instead of being straight, this sluice formed several angles in such a way that its head and lower end were in close proximity, so that ore, placed at its head, could be washed by water baled or otherwise raised from the well at its lower extremity. In this way a current was established, and the ore washed by a stream of water constantly returning to the wells to be again used.

The ore was smelted in small blast furnaces blown by hand bellows, the fuel being either wood or charcoal. The slags produced contained from 5½ to 14 per cent. of lead. The work lead, which M. Cordella has reason to believe averaged 0·4 per cent. of silver, or about 130 oz. per ton, was refined by cupellation. No part of the apparatus used for this purpose has been discovered, but the frequent occurrence of fused masses of desilverised litharge sufficiently proves the nature of the process by which it was obtained. The lead was assayed for silver in the usual way, and earthern cupels, of nearly the same form and dimensions as those now employed, have been found in the waste-heaps.

The period of the greatest activity at the Laurium mines, which, although belonging exclusively to the State, were leased to private individuals, was between 600 B.C. and the Peloponnesian War, a period of about 170 years. M. Cordella estimates the number of workmen employed at this date at 15,000, all of whom, including the foremen and superintendents, were slaves. During the Peloponnesian War, Laurium was cut off from the capital, and the slaves revolted, after which the mines were worked fitfully and upon a reduced scale, operations being sometimes restricted to the re-smelting of the old slags. The mines were also worked to some extent under the Romans, but only through the agency of Greek factors; and in the first century of the Christian era, Laurium was completely abandoned; nor is there any evidence that work was ever recommenced until the year 1864.

The aggregate amount of labour expended by the ancients was enormous; some 2,000 shafts, averaging about 250 feet in depth, have been found, and the extent of the underground workings is in proportion. The quantity of slag originally left was about 2,000,000 tonnes, which M. Cordella calculates must represent 2,100,000 tonnes of lead and 8,400,000 kilogr. of silver, in addition to which the ancient miners left behind them millions of tonnes of halvans in the form of waste-heaps, containing from 1½ to 18 per cent. of lead. The zinc ores were not worked.

Some idea of the general mode of occurrence of the ores will be afforded by the following section, Fig. 97, after Cordella, through the most important deposits of lead ore and calamine at Laurium.

In the above section, *a* represents a more or less ferruginous limestone; *b*, middle crystalline limestone, in places somewhat siliceous, and impregnated with sulphuretted ores; *c*, lower limestone (marble), which has not yet been sunk through by the new shafts; *d*, middle mica schist of Camaresa, with lenticular interpolations of limestone and quartz, including small lead veins. The thick upper mica schist, not shown in the section, rests on the upper limestone, *a*, of the Ripari Mountain.

A mica schist, *e*, of lesser thickness, almost always forms the hanging wall of the third contact deposit; *f*, is the upper ore bed or first contact bed; *g*, second ore bed; *h*, third ore bed, much worked by the ancients; *i*, calamine. This mineral occurs in all horizons, but is most extensively developed in the foot wall of the third contact bed, where, at Camaresa, it is from 3 to 24 feet in

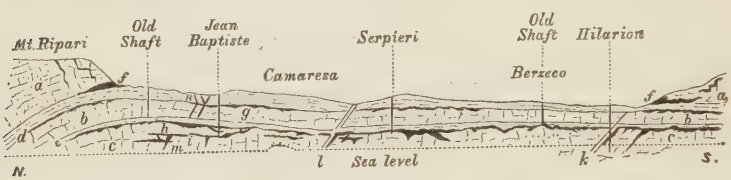


FIG. 97.—Laurium; vertical section.

thickness, and contains from 42 to 46 per cent. of zinc. Blende sometimes occurs with the calamine.

A granite vein, *k*, courses from east to west, and dips 40° north; it is more or less weathered, and forms the hanging wall of the first rich calamine deposit discovered by Cordella in 1869. The felsite dyke of Camaresa, *l*, 6 feet in thickness, traverses the entire mass, and contains rich lead ores under the third contact bed. Veins of calamine, *m*, coursing east and west, vary from 8 inches to 4 feet 9 inches in thickness and dip almost perpendicularly, those in the lower limestone, *c*, being of especial importance. Numerous small lead veins, *n*, were worked by the ancients.

Fig. 98 is a section, also after Cordella, of the Jean Baptiste shaft, 63 fathoms in depth, the mouth of which is 577 feet above sea level. In this section, *d* represents mica schist, 144 feet in thickness, enclosing lead veins, *n*; *o* is an old level about 13 fathoms from the surface; and *g*, the second contact lead bed, 18 inches thick. The limestone, *b*, is 103 feet in thickness; the mica schist, *e*, 4½ feet thick; and *h*, the third contact lead deposit, 16 feet in thickness.

The calamine bed, *i*, has an average thickness of 11½ feet, and *c*, is crystalline limestone.

According to Huet,[1] these deposits have been formed by currents of mineralising solutions rising through the fissures, and unable to penetrate the schists or the eurite, attacking the limestone and gradually forming a deposit of ore by incrustation and metasomatic substitution. The current then made its way through the overlying schists by narrow fissures in the latter, leaving no deposits in those beds because it found in them no soluble con-

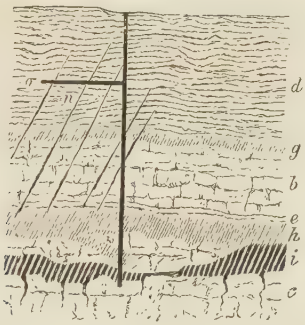


FIG. 98.—Laurium, Jean Baptiste shaft; vertical section.

stituents to be acted on, and expanded again in the upper limestones in an impoverished state and formed another poorer series of deposits at the upper contact.

The most important mining company is the "Société Française des Mines du Laurium" already referred to. The ores raised are galena and cerussite, very rich in silver, with blende and calamine; the number of miners usually employed is about 2,700.

The calamine of Laurium is richer than that of Sardinia, and is usually calcined previous to exportation. After calcination it contains on an average about 60 per cent. of zinc. The lead ores of Laurium are associated with blende, from which they are separated at ore-dressing works which have been erected for the purpose.

[1] Fuchs and De Launay, *Traité des gîtes Minéraux et Métallifères*, ii. p. 385.

The production of the mines of this company in 1881 was as follows:—

	Tonnes.
Roasted calamine	36,665
Raw calamine	101
Blende	246
Lead ores	1,543
Mixed ores	2,820
Iron ores containing manganese	847
Argentiferous lead	1,722
Total	43,944

In 1891 they produced 27,838 tonnes of zinc ore and 7,104 tonnes of work lead containing 1·72 kilogr. of silver to the tonne.

Various other mining companies are working in the district. such as the Sunium, the Austro-Belgian, the Pluto Company, the Société d'Olymp Lauriotique, &c., which, although they possess deposits of ore, have not as yet attained a large production.

In the Sunium Mine, first opened in 1873, sixty men are employed, and up to 1881 about 1,500 tonnes of zinc ore had been produced. The calamine here occurs irregularly at the surface, in limestone near the sea shore.

There are numerous deposits of similar ores in Greece, among which may be mentioned the irregular mass of zinc ore in limestone at Mount Hymettus, and the argentiferous lead and copper lodes traversing the limestones and mica schists of Karysto. These deposits contain quartz, galena, chalcopyrite, and iron pyrites. The ore worked contains from 15 to 20 per cent. of lead, and from 800 to 1,000 grms. of silver per tonne of lead. Numerous veins of argentiferous lead have also been discovered in the islands of Antiparos, Siphanto, Zea, Anaphi, Milo and Santorin.

Copper.—Copper ores have been discovered at different places, sometimes mixed with lead ore, and at others isolated in the state of sulphides and carbonates. At Laurium the lead ore is more or less cupriferous. The ore at the Jean Baptiste shaft sometimes contains from 6 to 12 per cent. of copper. At Karysto the galena contains from 5 to 18 per cent. of copper.

Manganese.—The Greek Government has of recent years granted a large number of concessions for so-called manganese mines; but the majority of them refer to iron ores, containing manganese, and suitable for the manufacture of Bessemer steel. In one of these mines only has pure manganite been found. At Andromonastiri, in Messina, rich manganese ore has been found, forming beds sometimes eighteen inches in thickness, in Cretaceous rocks; while at Perachora, in Corinth, a lode of good oxide of manganese has been discovered; and in Milo pure manganese ore has been found, forming irregular masses in trachyte.

Chromium.—Chromite frequently occurs in Greece, but in a very irregular manner, sometimes in the form of impregnations only, and at others at more or less considerable masses enclosed in serpentine. At Vattonde, in Eubœa, considerable quantities of rich chrome ore are worked; the ore occurring in the form of thick veins traversing green serpentine. The ores supplied by the mines of the Eubœa and Skyros are preferred on account of their superior quality; they produced 1,650 tonnes in 1878.

The limited employment of chromates, and the discovery of rich deposits in Thessaly and Asia Minor, which are worked open-cast, have, however, greatly affected the working of chrome mines in Greece, and the majority of them have been abandoned.

Iron.—Greece is rich in iron ores, and the occurrence of iron slags in various localities shows that the iron ores not utilised at the present day were extensively employed by the ancients. Large masses of such slags have been found at Karysto, Seripho, and in many other places. In the slag-heaps of Seripho, a Carthaginian coin was found dating from the fourth century B.C., the period at which it may be supposed that this establishment was in operation. The iron ores generally consist of iron carbonate, hæmatite and magnetite, forming irregular masses in the limestone, or at the contact of the limestone and mica schists. The greater portion of the ores contain manganese, those of Seripho yielding from 5 to 8 per cent. of this metal.

In 1869 a company was formed to work the ores of Seripho, where brown hæmatite was found near the sea shore in the form of contact masses from nine to forty-five feet in thickness. This ore, which contains 50 per cent. of iron and about 4 per cent. of manganese, much resembles the brown hæmatite of Bilbao in Spain. In the interior of the island masses of magnetic iron oxide exist in the immediate vicinity of granite, but have not been worked.

Cordella gives the following as the mineral production of Greece in 1877:—

	Tonnes.	Value.
Zinc ore	31,000	£104,400
Lead ore	860	9,120
Magnesite	1,500	1,800
Manganite	50	240

According to Dr. Gurlt, the average annual production of Greece in 1880 was about as follows:—[1]

	Tonnes.
Zinc ore	9,000
Lead ore	1,000
Chrome iron ore	2,000
Magnesite	1,500

In addition to this, 10,000 tonnes of argentiferous lead are produced annually at Laurium from the old slag-heaps.

In 1894[2] Greece produced the following metalliferous minerals:—

	Tonnes.	Value.
Iron ore	281,000	£94,500
Lead ore	6,250	30,550
Zinc ore	21,000	75,700
Manganiferous ores	9,300	10,800
Chrome iron ore	1,500	3,800

The total production of lead is given as 14,000 tonnes.

SPAIN.

Spain takes the lead of all other countries in the amounts of lead and quicksilver which it produces. The copper district of Huelva is one of the most important in the world, and the iron mines of Bilbao are famous both for the quantity and quality of their ores. The chief lead-producing province is Murcia, on the south-eastern coast, which affords two-thirds of the annual yield of the country, while that of Santander, on the Bay of Biscay, leads in the production of zinc ores. The provinces of Santander and Murcia, together, afford nine-tenths of all the zinc ores raised in

[1] Dr. A. Gurlt, *Glaser's Annalen*, 1882, No. 112.

[2] *Statistique de l'industrie minérale en France*, 1894. Appendix.

the country. Nearly the whole of the copper is obtained from the province of Huelva, in the extreme south-west adjoining the celebrated pyrites district of Portugal; while iron ore is extensively mined in the neighbourhood of Bilbao and in the province of Murcia.

Gold.—In Spain gold mines were successively worked by the Phœnicians, Romans, and Moors, and although the amount at present obtained is exceedingly small, it is believed that this country formerly yielded large quantities of the precious metal. Strabo and Pliny both mention Spain as a gold-producing country, and name various localities where it was obtained.

M. Piette, who has devoted much attention to the subject of ancient mining in the Peninsula, is of opinion that formerly both Spain and Portugal produced gold, and, further, that it was obtained, not only from washing the sands of valleys and rivers, but also from workings in the solid rock. His investigations, however, led him to the conclusion that if the auriferous regions were originally rich, they had become almost totally exhausted previous to their abandonment; since, during the whole of his examinations of the old workings, he met with only a few very slight traces of gold. Among the gold mines of the Peninsula, which have been worked in comparatively modern times, may be mentioned one near Talavera, and another at Domingo Flores in Leon, which was wrought, intermittently, during a period of nearly a hundred years subsequently to its commencement in 1639. The sands of the river Sil in Leon are known to be auriferous, and an English company was formed for the purpose of working placers in this valley, but the enterprise was not commercially successful. Affluents of the Sil, chief amongst which are the Burbia and the Anclares, also carry gold both in their beds and in the alluvial deposits on their banks. This region seems to have been thoroughly worked over during Roman times, and all recent experiments at working it have proved failures. The same may be said of the rivers Duerna and Eria. The presence of gold is undoubted, but as to whether enough has been left to form the basis of a payable industry, even with modern appliances, is a very different matter. Alluvial gold is also known to exist in the valleys of some of the smaller streams that divide Spain from Portugal, but beyond a little desultory washing by the inhabitants in the immediate neighbourhood, these deposits are unworked.

Silver.—The silver mines of Guadalcanal and Cazalla, north of Seville, occur in mica schist, and were formerly very productive, but are now of little or no importance; there were also formerly mines at a short distance from that city, which are said to have yielded large returns during some portion of the seventeenth century. Rich argentiferous galena is found in the Sierra Almagrera, and has been worked to a considerable extent.

The most important silver mines of modern times were, however, those of Hiendelaencina, situated in the province of Guadalajara, seventy miles north-east of Madrid. These mines were discovered near the village of Hiendelaencina in 1843, and shortly afterwards a concession was obtained, and a mine commenced, which, in honour of the patron saint of the village, was called Santa Cecilia. Of the other mines subsequently opened, the most remarkable were the Suerte, Fortuna, Verdad de Los Artistas, Relampago, San Carlos and Vascongada, all of which yielded large amounts of silver. There are numerous other lodes in the district, but only that on which the above mines are situated, was worked with advantage. Its direction is nearly east and west, with a dip to the south, and its average thickness is not quite two feet; the enclosing rock is gneiss, associated with mica schists. The gangue is heavy spar, but quartz and spathic iron also occur. The ores are principally argentite, freieslebenite, miargyrite and ruby silver ore, although galena, antimony glance, native silver and chloride and bromide of silver are likewise present. The average yield of the ores produced was about 90 oz. per ton.

The mines of Hiendelaencina, which were worked to a depth of 200 fathoms, began to decline in their yield in 1860, and in 1866 the majority of them had already suspended operations. Since that period, we are without any statistics relative to their production; but from the beginning of 1847 to the end of June 1866, the Hiendelaencina mines yielded 8,196,704 oz., Spanish, of silver, equivalent to 7,578,536 oz., English.

Lead.—Lead is found in all the provinces of Spain with the exception of Valladolid; but the most important deposits of lead ore are those of Jaen, Murcia, and Almeria.

The town of Linares, in the province of Jaen, is situated on a plateau of nearly horizontal sandstone of Triassic age, which has seldom a thickness exceeding thirty-five feet, and which reposes directly upon granite. Both the sandstones and granite are traversed by two distinct systems of lead veins, the more important of which strike either north-east and south-west, or east-north-east and west-south-west; a smaller number, however, of broader and more irregular veins, comparatively barren and coursing east and west, are met with on the slopes of the Sierra Morena north of Linares. The ferruginous quartz, which constitutes the outcrops of the more productive system of veins, frequently forms projecting crests through which are scattered grains of galena, which gradually become more numerous as greater depths are reached. Generally speaking, these lodes become productive at an inconsiderable distance from the surface, yielding galena, comparatively poor in silver, associated with blende, iron and copper pyrites, spathic iron ore, cerussite and calcite, enclosed in a predominantly quartzose gangue. No decrease in the width of the veins had been observed at a depth of 135 fathoms and, as a general rule, they were found to be richer in their broader than in their narrower parts. The ore chimneys or bunches are nearly vertical, and as the lodes often divide into branches and subsequently re-unite, it not unfrequently happens that rich bunches of ore are found at the point of junction with one another. The larger veins, coursing approximately east and west, are composed principally of quartz and heavy spar enclosing iron pyrites, copper pyrites, and galena, poor in silver. The outcrops of these veins sometimes project above the surface of the sandstone to a height of several feet; the ores being usually disseminated in strings instead of being concentrated in chimneys as in the case of the smaller and more productive lodes.

Among the undertakings under English management in this district are the Linares Mines, which yielded, in 1881, 4,312 tons of lead ore, while the mines of the Fortuna and Alamillos Companies produced respectively 4,344 tons and 3,533 tons during the same period.

The following table of the production of lead ore in the province of Jaen will give a good idea of its importance:—

1867 about	40,000 tonnes.
1870 "	67,299 "
1875 "	86,000 "
1881 "	118,325 "
1885 "	101,555 "
1890 "	116,240 "
1893 "	98,416 "

The Sierra de Cartagena[1] is composed of Silurian slates and limestones penetrated by trachytes and basalts, and surrounded at

[1] F. de Botella, *Descripcion geologica-minera de las provincias de Murcia y Albacete*, Madrid, 1868.

the base by rocks of Tertiary age. Both the Silurian rocks and the trachytes in the vicinity of Almazarron, some distance west of Cartagena, are traversed by a number of veins of which the direction approximates closely either to north and south or to east and west, and of which the dip is usually almost vertical. In the stratified rocks the ores occur partly in fissure veins and partly in strings or branches parallel to the bedding; they also form lenticular or bedded veins, which are sometimes of considerable extent and thickness. These deposits often enclose fragments both of slate and trachyte, and must consequently be more recent than the latter rock. They are usually composed of an irregular mixture of ferruginous silica with galena, iron and copper pyrites, mispickel, magnetite, calcite, heavy spar and quartz.

The broader parts of these veins are, for the most part, comparatively barren, while the narrower portions and the branches are often almost exclusively composed of various metallic sulphides. Two other forms of lead deposits occur in the province of Murcia; the one forming disseminations of galena, pyrites and blende, in a compact greenish rock, while the other occurs in the form of beds, or bedded veins, in limestone. This province produced about 170,000 tonnes of lead ores in 1893.

Connected with the deposits of lead ore are also deposits of zinc ores, which occur either as irregular masses of calamine at higher levels or of zinc blende, which mostly however occurs in fissure veins. The calamine deposits are rapidly approaching exhaustion, but the blende is still being freely mined. In 1893 Murcia produced about 10,000 tonnes of zinc ores.

The Sierra Almagrera rises in the north-eastern portion of the province of Almeria, forming a range of about 1,000 feet in height and fifteen miles in length, on the coast of the Mediterranean. Although it rises somewhat abruptly towards the south-east, the slope in the contrary direction, towards the plains, is extremely gradual. It consists chiefly of mica schist, passing into clay slate, and is frequently intersected by deep gorges, and traversed by numerous veins, the most remarkable of which is the Jaroso Lode, named after one of the neighbouring ravines. This lode, towards the north, splits into numerous branches, while to the south it is cut off by a fault. The portion which has been worked between these two points is about 2,100 feet in length. The strike of this vein is almost due north and south, with an average dip of 60° east; its greatest width is twenty feet, and it frequently includes fragments of the country rock. Heavy spar, spathic iron ore, calc spar, red and brown iron ore, argentiferous galena, and iron and copper pyrites form the filling of the fissure. This lode is distinguished for the combed arrangement of its constituents, and for the number and beauty of its crystallised minerals. The vein material to a depth of eighteen fathoms consisted, for the most part, of decomposed clay slate, hæmatite, limonite, and heavy spar; beneath this followed the most productive horizon containing rich argentiferous galena, with occasionally cerargyrite, associated with iron ores. Below the depth of eighty-two fathoms the proportion of silver began rapidly to decrease, while heavy spar and hornstone became predominant. B. v. Cotta suggests that the presence of very rich ores below the depth of eighteen fathoms, may possibly be accounted for on the hypothesis that the metals washed out of the gossans had become concentrated in this zone.

Although the combed structure of this lode is very remarkable, the arrangement of the several layers is by no means symmetrical, and it follows that they cannot have been the result of successive deposits on the sides of a single fissure. It may therefore be possible that the vein has been repeatedly fissured, and that the re-filling of these rents has resulted in the want of symmetry observed. This becomes the more probable from the circumstance that, in the middle of the lode, horses occur which at a certain period of its formation appear to have formed the wall of an adjoining comb. The province of Almeria produced about 35,000 tonnes of lead ores in 1893.

The importance of lead mining in Spain will be understood when it is stated that in 1881 that country produced 320,898 tonnes of lead ore, and that out of 59,905 persons who obtained their living by mining 18,969 were employed in lead mines. In 1894,[1] the total production of lead ores, including argentiferous lead ores is given as 322,557 tonnes, a marked falling off from the immediately preceding years.

Zinc.—The Cantabrian coast of Spain is rich in calamine, more especially the provinces of Guipuzcoa and Santander. At La Nestosa, Comillas, &c., deposits of this ore occur in dolomitic limestone of Jurassic age, partly in the form of veins, and partly as very irregular deposits, containing, principally, calamine and galena. The calamine is chiefly carbonate of zinc, although zinc silicate and snow-white zinc bloom are also of frequent occurrence. The ores are often embedded in clay, and the centre of large blocks is sometimes formed of dolomite, thus indicating the origin of the ore. At greater

[1] *Revista Minera*, Jan. 16th, 1896.

depths crystallised blende of a bright brown colour is found in concretionary masses, covered by concentric layers of heavy spar, or, near the surface, partly converted into zinc carbonate. Calamine was first discovered in the north of Spain in 1852, and in 1862 considerable attention had become directed to this region by the large and increasing quantity of zinc ores which were being sent into the market.

The zinc deposits in the provinces of Santander and Madrid are very fully described by W. K. Sullivan and J. P. O'Reilly.[1] These gentlemen conclude that the zinc carbonate, and perhaps also the lead carbonate, was originally precipitated from solution either by carbonate of lime or by dolomite. In some instances the replacement is so complete that calamine passes insensibly into pure dolomite, as at the Venta Mines, and still more strikingly at the Vicenta and Reocin Mines. Both the carbonates of calcium and magnesium appear to have taken part in the decomposition; but the magnesium carbonate, as the more soluble, appears to have been wholly removed, while some of the carbonate of calcium still remains filling joints, or forming a kind of conglomerate. In depth blende of a bright yellow colour is seen to replace the calamine to a great extent, so that whilst there is little or no doubt as to the metasomatic origin of the deposits, it is still an open question whether the ore was not originally all blende, which has subsequently become converted into calamine in the upper portions of the deposit, by the action of meteoric waters, possibly by the interaction of the sulphate of zinc produced by the oxidation of the blende with the carbonates of lime and magnesia, and more especially the latter. The highly soluble sulphate of magnesia thus formed would readily be leached out and removed.

The province of Santander produced 18,325 tonnes of zinc ore in the first six months of 1893, and the neighbouring province of Guipuzcoa, into which the same deposits extend, 3,878 tonnes in the same period.

Copper.—A zone of clay slate, 110 miles in length, courses in a north-westerly direction through the provinces of Huelva in Spain, and of Alemtejo in Portugal, and encloses enormous deposits of cupriferous iron pyrites.

In Spain the deposits of Rio Tinto and Tharsis are the most important. The age of the enclosing rocks is somewhat doubtful, many geologists believing them to be of either Silurian or

[1] *Notes on the Geology and Mineralogy of the Spanish provinces of Santander and Madrid*, London, 1863.

Devonian age. F. Römer[1] is of opinion that they belong to a low horizon of the Culm-measures. The latter opinion has been decisively corroborated by the researches of D. Joaquim Gonzalo y Tarin.[2]

Near the ore deposits, and parallel to them, dykes of quartz-porphyry often occur, and Spanish geologists have suggested a connexion between the two; this, however, Römer does not feel inclined to accept. These deposits of cupriferous pyrites consist of a series of more or less continuous lenticular masses running parallel with the bedding of the enclosing slate, sometimes extending to a great length, occasionally having a width exceeding fifty fathoms, and composed of an intimate admixture of iron pyrites with a little copper pyrites, through which strings of the latter mineral

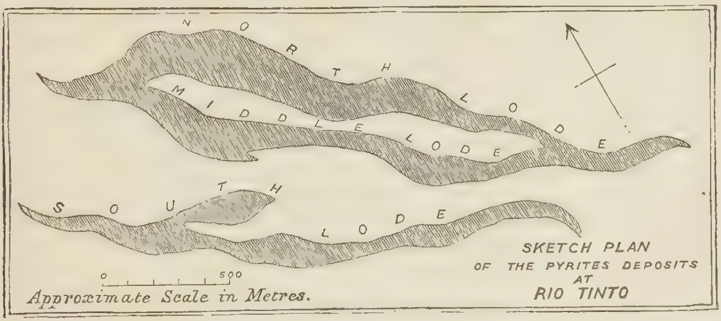


Fig. 99.—Pyrites deposits, Rio Tinto.

sometimes ramify. Small strings of black sulphide of copper less frequently traverse the mass.

The deposits are developed in the immediate neighbourhood of a series of dykes of porphyry that traverse the stratified rocks, and with the presence of which, that of the deposits is evidently very closely connected. Very often, as shown in the section, Fig. 9, page 41, these pyrites deposits occupy the zone of contact between the porphyry and the stratified rocks.

At Rio Tinto the deposits of cupriferous pyrites assume the form represented in Fig. 99. The slate, which stands nearly vertical, is altered in the immediate vicinity of the deposits by the action of the acid salts resulting from the decomposition of pyrites, and not only becomes softer but also assumes a yellowish-

[1] F. Römer, *Zeitscher. d. d. geol. Gesellsch.* 1876, p. 354.

[2] *Memorias de la Comision del Mapa Geologico de España. Descripcion de la Provincia de Huelva*, 1886, p. 496.

white or reddish-gray tint. This decomposition of pyrites proceeds with considerable activity, and it has been calculated that, since the mines were abandoned by the Romans, from 70,000 to 80,000 English tons of metallic copper must have been carried into the sea by the Tinto River.

The compact or finely crystalline pyrites, which frequently exhibits a stratification parallel to that of the country rock and exhibits similar joints and headings, contains, on an average, about 2½ per cent. of copper. Quartz, galena, blende and arsenical pyrites occur very subordinately, and drusy cavities are exceedingly rare. These deposits have, almost without exception, been wrought at a very early date, the workings having, in some cases, reached a depth of above fifty fathoms. These ancient excavations, the larger proportion of which are undoubtedly Roman, were confined to the branches of richer ore before referred to, which not only traverse the main deposit, but also sometimes extend into the quartz-porphyry forming one of the walls.

The Roman workings consist of numerous circular shafts, which are seldom more than thirty inches in diameter, in connexion with various tortuous galleries, which invariably follow the richer branches of ore. By becoming saturated with waters holding copper salts in solution, the ancient woodwork of the mines has been wonderfully preserved, while its tissues have sometimes become permeated with metallic copper, resulting from the reduction of its salts by woody fibre. In this way timber which has been employed for supporting the ground, is often so perfectly preserved as to retain markings and letters cut by Roman miners eighteen centuries ago.

The drainage was, in Roman times, effected by a series of wooden wheels with buckets, acting somewhat in the manner of the eastern *noria*, of which numerous remains have been discovered. Earthenware lamps of Roman workmanship are constantly found in the old workings, while implements and vessels of bronze have been occasionally met with. Still less frequently human bones have been discovered, which, by the action of copper salts upon their calcic phosphate, have assumed an appearance resembling that of turquoise. It may be here mentioned that some time ago a bronze plate was found at the entrance of a Roman gallery at Rio Tinto, recording the fact that it was commenced during the reign of Nerva, A.D. 96-98.

Up to the present time Rio Tinto has been extensively worked in open-cast, the ores being in part exported, and in part treated locally for the copper they contain by a process of solution and precipitation. The very extensive scale upon which operations are conducted at Rio Tinto will be gathered from the following figures. The amounts of pyrites which were produced during recent years were as follows:—

Year.	Quantities of Pyrites.[1]			Percentage of metallic copper.	Copper produced at the mines.
	Exported.	For local treatment.	Total produced.		
	Tons.	Tons.	Tons.		Tons of 21 cwt.
1876	189,962	159,196	349,158	1·5	946
1877	251,360	520,391	771,751	2·375	2,495
1878	218,818	652,289	871,107	2·78	4,184
1879	243,241	663,359	906,600	2·78	7,179
1880	277,590	637,567	915,157	2·865	8,559
1881	249,098	743,949	993,047	2·75	9,466
1882	259,924	688,307	948,231	2·805	9,740
1883	313,291	786,682	1,099,973	2·956	12,295
1884	312,028	1,057,890	1,369,918	3·234	12,668
1885	406,772	944,694	1,351,466	3·102	14,593
1886	336,548	1,041,833	1,378,381	3·046	15,863
1887	362,796	819,642	1,128,438	3·047	17,813
1888	434,316	969,317	1,403,633	2·949	18,522
1889	389,943	824,380	1,214,323	2·854	18,708
1890	396,349	865,405	1,261,754	2·883	19,183

In 1895 [2] the quantity of pyrites mined was 1,372,376 tons as against 1,387,095 in 1894, the percentage of copper being 2·821 in the former year as against 3·027 in the latter. The amount of pyrites exported was 518,560 tons in 1895 as against 485,441 in 1894. During the twenty-three years of the Company's existence over 23,000,000 tons of pyrites have been extracted, and it is estimated that there are another 135,000,000 tons now opened up.

In addition to copper, Spanish and Portuguese pyrites contains from 20 to 35 dwt. of silver per ton, together with traces of gold, both of which were, for many years, not utilised. These metals are now, however, recovered by the Claudet process, and in 1883 no less than 348,210 oz. of silver and 1,911 oz. of gold, which would otherwise have been lost, were thus obtained.

The Tharsis and Calañas deposits, both lying west of Rio Tinto, belong to the Tharsis Sulphur and Copper Company, and possess so close a general resemblance to those of the last-named locality as to require no special description. The total amount of

[1] *Revista Minera*, 1891, xlii. p. 134.

[2] Directors' Report for 1895.

pyrites extracted from the Tharsis and Calañas Mines during the year 1882 amounted to 486,860 tons, and shipment was made of 212,218 tons of pyrites and 5,534 tons of copper precipitate.

In 1895,[1] the total production from the Tharsis, Calañas, and Lagunazo Mines (the last a recent acquisition) was 612,483 tons, as against 588,427 tons in 1894. The amounts for export and for treatment at the mines were respectively 218,037, and 394,410 tons as against 208,362, and 380,065 tons respectively in 1894.

Quicksilver.—Mining for quicksilver was carried on at Almaden, in New Castile, at a very early period. Theophrastus speaks of the stony cinnabar of Spain, and Vitruvius mentions that cinnabar was found in that country and brought thence to Rome for treatment. Strabo states that this mineral was found in Turdetania (Almaden), and Pliny informs us that 10,000 lbs. weight of it was annually sent to Rome.

The quicksilver deposits of Almaden occur in Upper Silurian slates, which are sometimes interstratified with beds of limestone, but the slates themselves, which are much contorted, rarely contain cinnabar. The wall rock usually consists of black carbonaceous slates and quartzites, alternating with schists and fine-grained sandstones.

The deposits of cinnabar strike east and west, incline, near the surface, at an angle of about 65°, and then dip almost vertically. There are three deposits, of which the most important are the San Francisco and the San Nicolas, each of which has an average thickness of above 20 feet. They are sometimes divided from one another by only two or three feet of soft slate, and at the 135-fathom level are worked as one, the width of the common opening being 67½ feet. These deposits consist principally of quartzite, with either granular or compact cinnabar, which permeates the mass generally, or is besides concentrated in pockets and bunches, while the clefts and cavities, by which the deposit is traversed, often contain native mercury. At times geodes of calc spar are enclosed in the ore, which likewise contains iron pyrites and occasionally a little galena. In the year 1830 cinnabar in a stalactitic form was found in the Concepcion Nueva Mine, at Almadenejos; this, which was compact and of a yellowish-red colour, was probably a recent formation.

There has been much difference of opinion with regard to the nature of these deposits. Casiano de Prado,[2] who was for many

[1] Chairman's Report, *The Mining Journal*, April 25th, 1896.

[2] Don Casiano de Prado, *Minas de Almaden*, Madrid, 1846.

years director of the works, states that they exactly follow the strike and dip of the Silurian rocks, and he therefore calls them beds, but remarks that veins of cinnabar occur also to a subordinate extent in the immediate neighbourhood. He, however, considers it probable that the ores may have penetrated the slates from below; in that case they could scarcely be regarded as true beds. A. v. Groddeck classes them with bedded deposits, as does also Nöggerath, who studied the district in 1860 and 1861.[1] Hoppensack,[2] Willkomm,[3] and Le Play,[4] on the other hand, have regarded these deposits as lodes. The last-named author considers the vein-like character to be very evident, as he observed distinct quartz selvages separating the vein on both sides from the country rock. He also found in the so-called lodes fragments of a diorite which occurs in the immediate neighbourhood, and with the eruption of which he believes them to be intimately connected.

The generally received opinion at present appears to be that they are beds of quartzite that have been impregnated by solutions (or according to some by vapours) bearing sulphide of mercury, which have made their way through narrow fissures in the rock; these latter now appear as veinlets of cinnabar. No doubt the deposit is connected genetically in some way with the existence of the eruptive rocks in the immediate neighbourhood.

The richest ore obtained contains 25 per cent. of mercury, the average richness of the whole of the ore treated being 8·3 per cent. The average production of quicksilver at Almaden during the ten years, 1871 to 1880, was 36,000 flasks, weighing 1,242 tonnes. In 1876 seventeen mines yielded 26,323 tonnes of quicksilver ore, and, in 1877, 26,765 tonnes of ore were produced from eighteen mines.[5] In 1882 thirteen mines, employing 3,240 miners, afforded 27,037 tonnes of ore, worth £39,633.

In 1892 these mines produced 22,517 tonnes of ore, of which 19,588 tonnes were treated, producing 1,541 tonnes of metallic mercury. In 1894 the production of metallic mercury is reported at 1,536 tonnes, worth £203,500.

At Mieres in Asturias[6] mercury occurs in rocks of Carboniferous

[1] A. Nöggerath, *Zeitschr. Berg. Hütt. u. Salinenw.* x. 1862, p. 361.

[2] J. M. Hoppensack, *Ueber den Bergbau in Spanien überhaupt und den Quecksilberbergbau zu Almaden insbesondere*, Weimar, 1796.

[3] M. Willkomm, "Die Quicksilbergwerke zu Almaden," *Polytechn. Centralblatt*, 1849, p. 357.

[4] M. F. Le Play, *Annales des Mines*, v. 1834, p. 175.

[5] *Revista Minera*, 1883, p. 647.

[6] A. Dory, "The Occurrence of Mercury in the Asturias," *Rev. Univ. des Mines*, xxxii. Dec., 1895

ages, chiefly as cinnabar, but also as the black sulphide metacinnabarite, accompanied by realgar, orpiment, and metallic arsenic. At La Pena the ore occurs in a bed of breccia at its contact with the upper schists and quartzites of the Mountain Limestone, the bed being 60 to 90 feet thick; it also occurs in small pockets and bunches, filling cavities whose general direction is at right angles to the strike of the bed. At Pelugano the deposit takes the form of a contact deposit of which the Mountain Limestone forms the hanging and Devonian quartzite the foot-wall; at Lada, conglomerates of Carboniferous age and even three seams of coal are found impregnated with cinnabar. In other parts of the province limestones, sandstones, and metamorphic schists are found carrying cinnabar. The deposits have in all cases been formed epactically; according to A. Dory the mercurial ores have been deposited in some cases from solutions, in others from currents of gases and metallic vapours, which condensed in pre-existing cavities. The chief mine of the province is El Porvenir, which in 1893 treated 7,263 tonnes of ore and got 2,000 flasks (each of 34·503 kilogr. of mercury), and in 1895 got 1,260 flasks from 6,875 tonnes of ore. The following was the production of the chief mines in 1893:—

El Porvenir	2,000 flasks	Together with 150 tonnes of arsenical products, containing 90 % of arsenious acid.
La Union Asturiana .	900 ,,	
La Soterrana	300 ,,	
La Exploradora . . .	120 ,,	
La Concordia	100 ,,	

El Pelugano and La Minera were prospecting only.

The total production of the district from 1846 to 1893 has been 29,864 flasks.

Tin.—The Phœnicians are believed to have procured tin from Spain, and to have carried it to various ports on the Mediterranean. At the commencement of the Christian era the price of this metal was equal to about five shillings per pound, and it was consequently regarded as very valuable.

In Spain tin occurs both in veins and disseminated in alluvial gravels, and is most frequently found in the provinces of Orense and Pontevedra, where, within an area of twelve square miles, about thirty different lodes have at various times been worked since 1830. These veins, which seldom exceed seven inches in width, traverse mica schists and hornblendic rocks. The veinstone consists of quartz with a little mica, through which tin ore, wolfram and iron pyrites are sparingly disseminated. In the province of Salamanca there are, traversing the older slates, quartz lodes which contain tin ore, and in 1875 the tin mines of that region afforded employment to seventy workmen.[1] Near Cartagena tin ore occurs in lenticular deposits in Permian slate.[2] Tin ore has also been found in the province of Almeria.[3]

In 1880 one mine only was productive, employing four miners and yielding about 12 cwts. of black tin.

In 1893, the production was as follows:[4]—

		Tonnes.
Coruña	about	$2\frac{1}{2}$
Orense	"	15
Pontevedra	"	9
Salamanca	"	8
	Total for Spain	$34\frac{1}{2}$

The production is irregular, and the mines of the last named district have been shut down since 1893.

Antimony.—This metal occurs here as elsewhere in the form generally of sulphide, as stibnite; the largest productions seem to be in Huelva, but it is also worked in Leon and Oviedo. A good deal of stibnite has been worked in the Ribas valley in the Catalan Pyrenees. The deposits occur in a belt of metamorphic schists and shales, traversed by veinlets of quartz carrying stibnite; the general direction of these veins is between W. 10° S. – E. 10° N. and S.W. – N.E., the dips varying, but generally steep. The shale itself runs about S.W. – N.E., standing almost vertical, and for a breadth of about one metre seems to be mineralised by veinlets of quartz with stibnite and by pockets and impregnations of that mineral, the walls of the veins being nowhere well defined.

An interesting and perhaps unique occurrence of clay shales, mineralised by impregnations of native antimony,[5] also exists near Vinuela, in the province of Malaga; the metal occurs in crystalline masses, varying from about the size of an egg down to minute metallic spangles. This deposit is not at present worked.

Iron.—The value of the Biscayan deposits of iron ores has

[1] Massaret, *Ann. Soc. Geol. Belg.* 1875, ii. p. 58.

[2] M. Garcia, *Boletin de la Comision del Mapa Geológico de España*, iii. 1876, p. 2.

[3] *Revista Minera*, 1821, p. 148. B. v. Cotta, *Die Lehre von den Erzlagerstätten*, 1861, ii. p. 457. E. Reyer, *Zinn*, 1881, p. 154.

[4] *Comision Ejecutiva de Estadistica Minera*, 1894.

[5] Private communication from Mr. F. E. Harman, F.G.S.

been long appreciated, but it is only within recent years that their development has attained really enormous proportions. The most important of these deposits are situated on the left bank of the River Nervion, above the town of Bilbao,[1] and range, approximately, south-east and north-west, the rocks associated with them belonging to the Cretaceous period.

Although the iron ores of this district have long been known, it was only after the end of the Carlist war that their export assumed important dimensions. Thus in 1850 there were about 3,200 tons of ore produced, and 250,000 in 1870; the export of iron ore since 1877 is shown in the following table:[2]—

	Tonnes.
1878	1,224,730
1879	1,117,836
1880	2,345,598
1881	2,500,532
1882	3,692,542
1883	3,378,234
1884	3,155,432
1885	3,295,982
1886	3,160,047
1887	4,170,422
1888	3,591,637
1889	3,885,612
1890	4,272,918
1891	3,316,464
1892[3]	3,854,872
1893	3,953,475
1894	4,121,354
1895[4]	4,032,846

The number of men employed of recent years has been about 7,000; the total production of iron ore in 1893 was 4,571,800 tonnes, whilst in 1881 it was 2,800,075 tonnes.

There are various groups of mines into which this district may be divided, the most important being Somorrostro, Triano, and Matamoros, which produce over 90 per cent. of the entire output. The ores found in these deposits are known locally as:—*Campanil*, red hæmatite; *Rubio*, brown hæmatite; *Vena dulce*, a soft

[1] W. Gill, *Journal of the Iron and Steel Inst.* 1882, p. 63.

[2] *Revista Minera*, 1892, xliii. p. 94.

[3] *Journ. Iron and Steel Inst.* 1895, ii. p. 623.

[4] *Ibid*, 1896, i. p. 566.

rich ore; and *Carbonato de hierro*, spathic iron ore. The spathic iron ore has not yet been exported.

The *Campanil* has hitherto been found under workable conditions only at Triano and Somorrostro, and forms but a small proportion of the whole; but as this mineral is most in request, it has disappeared more rapidly than the brown ore. It is slightly inferior to the *Rubio* in percentage of iron, but its freedom from silica renders it specially valuable.

The *Rubio* is a hard brown ore, and, when of good quality, is richer in metallic iron than the *Campanil;* but from its association with siliceous matter, and, occasionally, with pyrites, it requires careful selection. It also contains more moisture than the other ores. The *Rubio* deposits are sometimes very deceptive, and what appear to be mountains of ore turn out to be merely shells of good mineral, with poor siliceous material beneath.

The *Vena dulce* is soft, of a deep purple colour, very rich in iron, and has been worked for centuries, by means of galleries and other underground excavations. This ore is seldom wrought separately excepting in small quantities for special purposes, or for treatment in Catalan forges, or by the Chenot process.

The *Carbonato de hierro*, spathic iron ore, occurs in both red and brown ore mines, but the most extensive deposits of it yet found are in the latter, where it underlies the *Rubio.*

In the classification given above, the term *Vena* includes other and harder forms of this ore, known locally as *Vena acampanilada*, *Vena rubiada* or *Rubio avenado*, according as it partakes of the nature of *Campanil* or *Rubio* respectively. The relation of these ores to one another, together with their order of succession, has not been thoroughly investigated; no geological survey has been attempted, and no deep borings have been made. There seems to be no absolute rule as to the relative positions of the *Rubio* and the *Vena;* in some mines the latter will underlie the former, the ore growing purer as it descends. Both orders of position are observable in the Matamoros district. Certain of the rugged escarpments of *Rubio*, which form such remarkable features of the brown ore mines, have probably been at one time covered with *Vena;* which, being the softer ore, has been washed out. The two ores are often, but not invariably, separated by beds of clay.

The accompanying analyses give the average composition of the ore raised in the Orconera Company's mines.

	Red Ore.	Brown Ore.	
Ferric oxide	78·03	79·96	78·29
Alumina	0·21	1·44	1·15
Manganous oxide	0·86	0·70	0·74
Lime	3·61	1·00	0·50
Magnesia	1·65	0·55	0·02
Silica	5·91	8·10	8·80
Sulphuric acid	0·01	0·10	0·05
Sulphur	trace	0·05	0·04
Phosphoric acid	0·30	0·03	0·02
Carbonic acid	5·00	—	—
Combined water	4·60	8·25	10·55
	99·91	100·18	100·16
Metallic Iron	54·62	55·97	54·80

The little that is known of the geology of the district has been gathered from the studies of M. Colette in 1845, and of Don Ramon de Adan y Yarza in 1877. Some notes upon the nature and formation of the ore deposits have also been published, in 1878 and 1879, by M. Bourson and M. Baillis. The investigation has, however, only been partial, and the inferences drawn have not been entirely confirmed by subsequent experience.

According to Mr. Kendall[1] the rocks of the district, which are of Cenomanian age, consist of a bed of limestone some 250 feet thick lying between a calcareous shale and a micaceous sandstone which is also in places calcareous, at steep and irregular angles of dip. The ore deposits are confined entirely to the limestone bed and are wholly within it, the longest, that of Triano, being about two miles long, five-eighths of a mile broad, and 220 feet thick in the widest part; the larger axis of this deposit, as in the case of most others of the district, is parallel to the strike of the strata. Sometimes the limestone has been weathered away entirely from an ore deposit, but the horizon of the latter can then be found by means of the bed of dark micaceous sandstone which forms its floor. It seems most probable that these deposits have been formed by the metasomatic replacement of the limestone, which was more or less completely converted into carbonate of iron by the action of iron-bearing solutions, whilst the carbonate was in turn more or less completely changed into brown and red hæmatites by the action of meteoric waters carrying carbonic acid and oxygen in solution.

Of recent years considerable attention has been paid to the

[1] J. D. Kendall, *The Iron Ores of Great Britain*, 1893, p. 265.

deposits of iron ore found in various parts of the south of Spain; these occur in the provinces of Murcia, Almeria, Malaga[1] and Sevilla, whose approximate production is as under:—

	1891.	1892.	1893.
	Tonnes.	Tonnes.	Tonnes.
Murcia	350,000	388,000	300,000
Almeria	163,200	174,350	115,000
Malaga	99,600	70,700	55,000

Sevilla produced very little until 1895 when about 100,000 tonnes of ore were raised. The deposits at Porman near Cartagena appear to be masses or bedded deposits in, or connected with, limestones; some iron ore also occurs in fissure veins, but this has not been greatly worked. In Almeria there are numerous deposits of which Herrerias in the Sierra Almagrera, and the Sierra de Bedar (often spoken of as Garrucha ore from its port of shipment), are the most important. In the former place the ores, consisting of red hæmatite and manganiferous iron ore, appear to form beds between strata of schists, whilst in the Sierra de Bedar the ores are chiefly brown and red hæmatite associated with mica schists and with limestone.

In Malaga the best known deposit is that at Marbella, whence 96,529 tonnes were imported in 1891. The ores of Malaga are almost exclusively magnetites of high quality. They occur in rocks of archæan age consisting of dolomite, gneiss, amphibolite, mica schist and serpentine.[2] The ores seem to be mostly, if not invariably, connected with the dolomite beds, occurring generally at the contact of these beds with serpentine in the form of irregular bedded veins, often lying at steep angles. The chief deposit at Marbella is 800 feet long, 200 feet broad and 420 feet deep. Mr. Kendall believes these ores to have been formed metasomatically, replacing beds of dolomite wholly or in part, and that their conversion into magnetite took place at a subsequent period, due probably to the same action that metamorphosed the surrounding rocks.

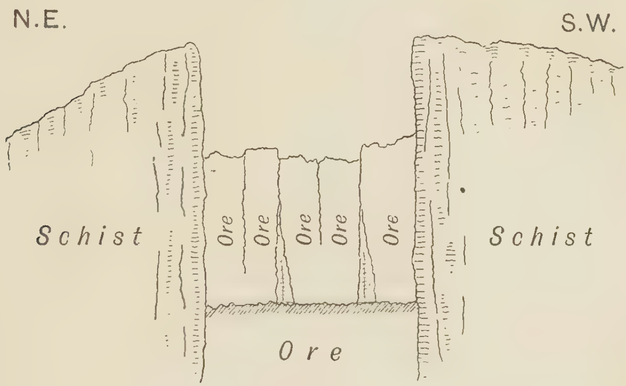
In Sevilla there are a series of deposits extending from the banks of the Guadalquivir northwards to past Guadalcanal, a

[1] A. P. Wilson, "The Iron Ores of the Mediterranean Seaboard," *Journ. Iron and Steel Inst.* 1894, ii. p. 183.

[2] J. D. Kendall, *The Iron Ores of Great Britain*, 1893, p. 273.

distance of about thirty miles. The most important of these deposits are those on the Monte de Hierro worked by Messrs. Baird and Co., Limited. They consist of a series of large irregular deposits either enclosed in crystalline white limestone, supposed to be of Upper Silurian age, or else developed at the contact of this limestone with overlying shales. An immense amount of ore has been found by boring, but the slope and dimensions of the deposits are not yet known. The ore consists of specular ore and hæmatite of good quality, but somewhat contaminated with barytes in the upper parts of the deposit. The passage between the limestone and the ore is quite gradual, and the latter seems to have been formed by metasomatic action upon the limestone. The formation of specular ore is probably due to the same forces that induced the metamorphism of the enclosing limestone. At Guadalcanal, further to the north, there are similar deposits, but apparently on a somewhat smaller scale, in limestone of similar character and probably of the same age. These deposits have been worked to a small extent to supply iron ore as a flux for smelting silver-lead ores. Further south and about forty-two miles from Seville, near the village of El Pedroso, are a number of apparently smaller deposits, which are either veins or bedded veins in schists of probably pre-Cambrian age, with occasional belts of limestone. These schists are traversed by a variety of porphyritic dykes and are almost vertical, resting against a huge mass of granite to the westward. The deposits are practically parallel to the stratification, running about north-west and south-east; the chief deposits are those of the Lima and of Juan Teniente, and consist of red and brown hæmatite and occasionally specular ore. A typical section of the Juan Teniente Mine is shown in the accompanying sketch Fig. 100. There are also a series of magnetite deposits that seem to follow a somewhat different direction, and which appear to be associated with igneous rocks. These magnetites show in places traces of cupriferous minerals, chiefly malachite and native copper. Too little work has been done on these deposits to enable any very definite opinion to be formed as to their nature; they are all, however, almost certainly epactic, and probably much more recent than the encasing rocks. Similar deposits occur at Rosalina and Monte Agudo. At Navalazarros a large irregular mass of magnetite occurs in an altered rock that was probably originally a diorite. Several of these deposits were worked at one time in order to supply a small charcoal blast furnace, but the district is now being regularly developed. The only mine that has made shipments is the Monte de Hierro, which produced about 100,000 tons in 1895. The ore is of high quality.

In the year 1880, there were 3,565,338 tonnes of iron ore produced in Spain from 774 iron mines, employing 14,795 workmen. The exports during the same period were 2,932,998 tonnes of iron



Scale 1 inch = 20 feet.

FIG. 100.—Section across Juan Teniente Mine.

ore, and 3,766 tonnes of pig iron. In 1894[1] Spain produced 5,352,353 tonnes of iron ore, worth £666,000; the production of pig iron in the same year was 123,798 tonnes. In 1895,[2] the export of iron ore from the whole of Spain amounted to 5,248,192 tonnes, whilst pig iron was also exported to the amount of 22,669 tonnes, as against 48,538 tonnes exported in 1894. It need hardly be said that the regular manufacture of pig iron for export is not a Spanish industry.

Oxide of manganese, of which one or two thousand tonnes are annually produced in Spain, is found in irregular pockets presenting no peculiar features. Its production varies, however, within very wide limits, being given for instance as 6,839 tonnes for 1892.[3] The bulk of this is produced in Huelva, a very small quantity coming from Almeria.

[1] *Revista Minera*, Jan. 16, 1896.
[2] *Journ. Iron and Steel Inst.* 1896, i. p. 565.
[3] *Comision Ejecutiva de Estadistica Minera*, 1894, p. 32.

General Summaries of the Production of Metalliferous Minerals in Spain during the Years 1882 and 1893.

1882.[1]

Description of Ore.	Quantities.	Values.	
	Tonnes.	Pesetas.	£
Iron ore	4,726,293	11,767,004	470,680
Lead ore	341,818	44,949,117	1,797,964
,, argentiferous.	22,425	4,876,971	195,078
Silver ore	18,349	1,779,154	71,166
Gold ore	360	9,000	360
Copper ore	1,720,853	18,897,598	755,904
,, argentiferous	50	50,000	2,000
Tin ore	0·23	250	10
Zinc ore	57,353	1,928,810	77,152
Quicksilver ore	27,037	990,841	39,633
Antimony ore	30	6,450	258
Cobalt ore	40	26,170	1,046
Manganese ore	5,668	227,897	9,115
Total value of Metalliferous Minerals produced in 1882		85,509,262	3,420,366

1893.[2]

Description of Ore.	Quantities.	Values.[3]	
	Tonnes.	Pesetas.	£
Iron ore	5,419,071	20,282,732	676,091
Argentiferous iron ore .	873	4,363	145
Wolfram ore	19	4,876	163
Iron pyrites	220,000	550,000	18,333
Ochre	1,030	3,550	118
Lead ore	169,707	16,318,238	543,941
Argentiferous lead ore.	179,458	20,698,448	689,948
Silver ore	4,825	1,285,206	42,840
Copper ore	15,219	139,503	4,650
Cupriferous iron pyrites	2,144,908	10,758,014	358,600
Copper and Cobalt ore.	1,116	133,920	4,464
Nickel ore	31	4,585	153
Nickel and Cobalt ore .	38	4,005	134
Cobalt ore	18	972	32
Tin stone	34	18,053	602
Arsenical pyrites . . .	160	1,622	54
Zinc ore	62,616	1,935,506	64,517
Mercury ore	34,309	8,090,937	269,698
Antimony ore	88	13,918	464
Manganese ore	1,460	38,330	1,278
Total value of Metalliferous Minerals produced in 1893		80,286,778	2,676,226

[1] "Estadistica Minera de España correspondiente al Año 1882," *Revista Minera*, 1883, p. 647.

[2] *Comision ejecutiva de Estadistica Minera. Año natural de* 1893, p. 147.

[3] Exchange taken at 30 pesetas to £1 sterling.

PORTUGAL.

Almost all the known geological formations are found in Portugal. One third of its area consists of igneous rocks, a second third is composed of the more ancient sedimentary deposits, and, finally, Tertiary and alluvial deposits occupy large areas near the centre of the country, besides being less plentifully disseminated in other parts of the kingdom.

Although these various formations contain important deposits of valuable ores, the literature of the subject is extremely scanty, being, according to M. F. d'Albuquerque d'Orey,[1] the author of a valuable memoir on the mineral resources of Portugal, confined to the catalogues of the Paris Exhibition of 1867, and of the Philadelphia Exhibition of 1876. For the purposes of this memoir the author referred to, availed himself of certain official MSS. in the Government Mining Bureau, to which, with the exception of what relates to the mines of San Domingos, I (J. A. P.) am indebted for the figures quoted.

Many of the more important ore deposits of Portugal were worked successively by the Phœnicians, Carthaginians, and Romans, but the circumstance that until the early part of the present century all minerals were regarded as national property, the ownership being vested in the Government, tended to materially retard the progress of this branch of industry. In 1852, however, the mining laws were revised and reformed, and from that year recent mining in Portugal may be said to date.

Gold is found in small quantities in the sands of some of the rivers, but the amount collected is so insignificant as to be of no commercial importance. Small quantities of gold are also occasionally extracted from the antimony veins at Valongo. As already mentioned, it occurs mainly as placer gold in some of the streams that form the boundary between this country and Spain.

There are no deposits in Portugal of silver ores proper, but this metal occurs to a small extent in association with ores of lead and copper.

Lead, Zinc and Antimony.—Lead occurs in various localities,

[1] "Die Bergwerks Industrie in Portugal," *Berg. und Hüttenm. Zeit.* 1881, p. 201, &c.

the deposits, to some extent, resembling those of Spain. The principal lead districts are those of Villa Real, Vizeu, Aveiro, Portalegre, and Beja. The most important lead-mining area is apparently that of Mertola, near the Guadiana, where the galena contains about 24 oz. of silver per ton, while the cerussite and anglesite, &c., which accompany it are sometimes much richer. Zinc ores are not known to occur in Portugal in workable quantities, but blendes so argentiferous as to be classed as silver ores have sometimes been found. Ores of antimony, chiefly in the form of sulphides, occur in three different regions, and occupy as many distinct geological formations.

In the district of Evora, antimony ore occurs in a quartz lode at the contact of Palæozoic beds and granite.

The principal antimony veins in the neighbourhoods of Valongo, Paredes, and Gondomar in the district of Oporto, may be divided into two systems characterised by different strikes. The deposits coursing N. 10° to 20° W., may be described as bed-like lodes, since their strike is identical with that of the country rock. The other system courses N. 30° to 60° E., and both occur in Silurian rocks. A third region of antimonial ores is situated near the town of Alcoutim, in the district of Faro, where there are two distinct lodes, one coursing east and west, and the other north-west. The latter has the same strike as the country rock, and is the only one now worked. These lodes occur in the slates of the Culm formation, and their production was formerly greater than it is at the present time.

Copper.—Numerous copper veins occur in granites and porphyries in the district of Evora, and another important deposit is that of Palhal, in Aveiro, which, in addition to copper, contains small quantities of nickel and cobalt. The most important copper deposits are, however, those of San Domingos, Aljustrel, and Grándola, enclosed in the great metalliferous belt extending into Portugal from the Spanish province of Huelva.

The celebrated mine of San Domingos, which produces the principal portion of the cupriferous pyrites raised in the country, is situated in an arid and rocky district nine miles from the Guadiana River and about thirty miles from the sea. The lithological characteristics of this part of the country are almost identical with those of the metalliferous district of Huelva in Spain, and the ore deposits, of which the strike is west-north-west and east-south-east, are probably of the same age. The ore, which is a cupriferous iron pyrites, yields, by dry assay, about $2\frac{1}{4}$ per cent. of copper, but contains less arsenic and somewhat less silver than some of the Spanish ores.

San Domingos, like Rio Tinto and Tharsis, was extensively worked by the Romans, who, from the coins which have been found in the various excavations, appear to have occupied this locality from the latter portion of the reign of Augustus down to the partition of the Empire under Theodosius, a period of about three and a half centuries.

In the valley into which the drainage level empties itself, rows of sarcophagi, still containing bones, have at various times been found, while in other excavations, cinerary urns and other indications of cremation have been repeatedly met with.

Among the relics which have been found of ancient mining operations, the most interesting was a series of large drainage wheels of wood in a state of perfect preservation. These wheels, to the number of ten, were furnished with buckets on their circumference for the removal of water; eight of them being sixteen feet in diameter, while the other two had a diameter of twelve feet only.

The quantity of pyrites extracted from this mine from the date of its being first opened to the end of 1877, has been approximately as follows:—

Ancient excavations estimated at 150,000 cubic metres; modern excavations 659,671 cubic metres. Total 809,671 cubic metres, or about 3,578,475 English tons.

During the year 1882 the output of pyrites from San Domingos amounted to 405,029 tons, in addition to which about 5,000 tons of copper were obtained in the form of precipitate from the local treatment of the ores. In 1887 about 350,000 tons were produced, and in 1895 the output was 185,463 tons of pyrites, as against 196,922 tons in 1894. The value of these copper ores constitutes about nine-tenths of the total value of the metallic minerals produced in Portugal.

Copper ore deposits likewise occur in the province of Algarve, at the contact of Jurassic and Triassic rocks, where they are traversed by dykes of diorite and serpentine. These deposits, which contain magnetite, in their geological and mineralogical characters somewhat resemble the deposits of Traversella, and of Monte Catini in Tuscany. They, however, contain comparatively little copper, and the mines once opened upon them are now abandoned.

TIN.[1]—Tin ore occurs in Portugal in various localities, especially

[1] E. Reyer, *Zinn*, 1881, p. 155.

in the provinces of Beira, Minho, and Tras-os-Montes, where it is found in alluvial gravels, in the form of stockworks in the granite, and as tin veins in the older slates. Tin mines were worked in Portugal in the time of Agricola, and tin-streaming, on a small scale, is one of the oldest industries of the country.

Eschwege[1] found tin ore in the sands, as well as in the granites, of Valongo, and established stream-works with considerable success; but the unsettled state of the country is said to have ultimately brought the enterprise to a standstill.

There are no available statistics relative to the present annual yield of tin ore, but the value of the yearly production has been estimated at £450. In 1874 tin mines were worked in the province of Tras-os-Montes to the depth of about twenty-five fathoms, but were ultimately abandoned as unremunerative. The quantities of ore produced are small but variable; thus the production for 1892 is given as 18 tonnes and for 1894 as 26 tonnes of tin ore.

Iron.—Portugal is rich in iron ores of good quality, large and important beds of this mineral occurring in almost all parts of the kingdom; however, with but few exceptions, all the iron mines of the country are now abandoned. The exportation of a few thousand tons of iron ore to England represents the whole of the production of the mines of Portugal. This is accounted for by the poverty of the country in coal, and by the absence of forests, resulting from the extravagance of former generations.

Among the iron ore deposits of Portugal the following are the most important, namely :—the hæmatite bed of Quadramil, in the province of Tras-os-Montes, which may be followed for a distance of five miles. It is frequently sixty-six feet in thickness, and occurs in Laurentian rocks. The iron ore veins in the Braganza district, Tras-os-Montes, now produce less than 200 tons of ore per annum. The iron ore deposits of Moncorvo, also in the same province, consist of a number of lenticular deposits, coursing north 70° in Laurentian rocks. These beds have a gentle dip, are frequently traversed by quartz veins, and are sometimes as much as 328 feet in thickness. They contain both red iron ore and magnetite; and large masses of ore which have become detached from the outcrops by former rains, have formed, in the valleys, extensive surface deposits which have been estimated at ten million tons. The iron ore in the beds themselves is estimated at least at fifteen million tons, and contains from 39 to 59 per cent. of iron.

[1] *Karsten's Archiv.* 1835, p. 221.

In the district of Odemira, in Alemtejo, iron and manganese deposits occur as lodes, as surface deposits, and as deposits of sandstones containing iron. The lodes, which traverse Laurentian limestones and slates, are very wide, and contain hæmatite, pyrolusite, heavy spar, and quartz. The production of this district attained its maximum in 1874, when 40,496 tons of iron ore were produced, and from that date to 1877 has rapidly decreased, the present output being exceedingly small.

MANGANESE.—In Portugal ores of manganese frequently occur in association with iron ores, but there are also deposits containing manganese ores only. These are principally found in the province of Alemtejo, where they occur in a zone about twenty-four miles in length between the towns of Mertola and Grandola, parallel to which are the celebrated pyrites deposits of Rio Tinto, Tharsis, and San Domingos. Manganese ores here form lenticular beds coursing N. 40° W., in Silurian and Lower Carboniferous strata, and are usually accompanied by beds of quartzite; manganese ores also occur in the form of lodes traversing quartzites. The ore is pyrolusite, and with it occur red hæmatite and heavy spar, while the country rock, as before stated, is quartzite. In 1875 twelve mines were working in this district, and the Paço Mine alone produced 812 tonnes of ore, and employed sixty workmen. No official returns are made of the metalliferous minerals annually produced in Portugal, but there being no smelting operations carried on at all, none of the ore raised is treated in the country, and the production of ores may be taken as equal to the quantities exported. According to the official customs returns, these were as follows for the year 1894:—

Description of Ore.	Quantities.	Values.[1]	
	Tonnes.	Milreis.	£
Antimony ore	396	21,137	4,227
Lead ore	755	20,196	4,039
Copper ore	228,777	2,018,613	403,723
Iron ore	223	2,480	496
Manganese ore	5,500	54,425	10,885
Not specified	1,261	47,950	9,590
Total value of Metalliferous Minerals exported in 1894		2,164,801	432,960

[1] Exchange is calculated at 1 milreis = 4*s*.

SCANDINAVIA.

Scandinavia is to a large extent composed of the older crystalline rocks, such as granite, gneiss, mica schist, chlorite schist, talc schist, hornblende schist, crystalline limestone, dolomite, &c., which are frequently traversed by porphyries, gabbros, basalts, and other igneous rocks. Overlying these rocks are strata of Silurian and Devonian age, which in some districts cover considerable areas, but the more recent sedimentary rocks are represented only in the most southern portion of Sweden. True veins are not of frequent occurrence among the ore deposits of Scandinavia, since the majority of them are bedded veins, whilst many are associated with bed-like masses called *Fahlbands.* Iron and copper ores are the most important, after which come silver and cobalt ores; and then, very subordinately, lead, zinc and nickel ores.

NORWAY.

The fundamental rocks of Norway are assigned by Norwegian geologists to the Azoic epoch, in which are included the Archæan rocks,[1] as well as the earlier gneiss. The close of the Archæan period in Norway was marked by eruptions of granite, which in some cases form extensive ranges of hills, while in others they constitute irregular detached masses. These granites are frequently accompanied by gabbros, and both appear to have exercised an important influence upon deposits of ore. Immediately after the great changes produced by the eruptions of granite, and possibly even while they were still in progress, the deposition of beds of Taconic age commenced.[2] These beds, of which there are three, rest unconformably on the older rocks. The second member of the series has been identified as corresponding to the Potsdam sandstone of the United States. The Taconic beds cover a large proportion of the area of Norway. The Silurian and Devonian formations occur mainly in two considerable areas, the one at and north of Christiania, and the other near the most southern limits of the country.

[1] O. G. Broch, *Le Royaume de Norvège et le Peuple Norvégien*, p. 106.

[2] Taconic, a term applied by Professor Emmons to certain rocks east of the Hudson, which consist of slates, quartz rock, and limestone, of Lower Silurian or upper Cambrian age.

Four outbursts of Plutonic rock are recognised as having taken place in Norway; namely, a Pre-Taconic, a Post-Taconic, a Silurian, and an eruption of Post-Devonian age. Throughout Southern Norway the formations from the Devonian to the Post-Tertiary are entirely wanting.

GOLD.[1]—Although Norway has never been an important gold producer, it has long yielded small but unknown quantities of that metal. The archives in Christiania show that gold was found in Norway in the reign of Christian IV., and in the seventeenth century two mines were worked for gold near the famous Kongsberg Silver Mines; it may be mentioned that one of these latter mines is now producing silver rich in gold. In 1705 native gold was found in the Aardal Mines, at the end of the Sogne Fjord, and in 1758 several thousand grammes were extracted from quartz mined near Eidsvold. Several Norwegian rivers, especially in the north, have been found to carry gold; thus men working in the Tana River were able to pan out a little over a pennyweight per man per day. Most of the copper produced carries gold, sometimes in sufficient quantity to pay for extraction.

The only gold mine properly so called at present working, is that owned by the Oscar Company, now known as the Bremnæs Gold Company, Limited, on the island of Bömmel, on the west coast of Norway, about midway between Bergen and Stavanger. The prevailing country rock is a saussurite gabbro, in which large masses and dykes of quartz porphyry occur; on the south of the district there is a large tract of finely crystalline slate, the quartz veins in which do not appear to be auriferous. The gabbro is also traversed by eruptive "slate dykes," containing much chlorite, calcite or dolomite, and which are supposed by Dr. Reusch[2] to be altered dioritic rocks; the quartz prophyry passes in places into what has been provisionally classed as epidote granite, or plagioclase granite according to Dr. Reusch. The rocks have been highly, and perhaps repeatedly, metamorphosed, and their relations to each other are obscure. Notably the dioritic slate dykes, and also the quartz porphyry, are traversed by quartz veins, somewhat lenticular in character as a rule, often broken and faulted in some cases by the intrusion of dykes. They are thus older than one series of dykes and younger than another. There are a number of these veins, some eight of which are well marked;

[1] For the greater part of the information respecting gold in Norway, I am indebted to the kindness of Mr. John Daw, jun.—H.L.

[2] Dr. Hans Reusch, *Bømmeløen og Karmøen*, Kristinia, 1888, p. 392.

some of them have been traced for over two miles, whilst croppings of auriferous quartz are known on the mainland some ten miles distant. The walls of these veins are generally diorite on one side and porphyry on the other, but they are found traversing all the rocks already named. The walls are generally well defined, and the width of the veins varies from four inches to six feet; the average is about three feet, and the richer portions rarely exceed a foot in width. Their strike is about N.E. and S.W., the dip being S.E. 25° to 45°. Most of the quartz is more or less auriferous, but the richer portions are concentrated in shoots dipping northwards, their average richness being $\frac{1}{4}$ oz. to 1 oz. per ton. The minerals accompanying gold are quartz, calcite, chlorite, chalcopyrite, pyrites, galena, occasionally telluride of bismuth, whilst native silver has been found, but only as a curiosity. It is noteworthy that coarse gold is rarely seen in those veins that run through the porphyry, whilst telluride of bismuth has only been found in those penetrating the gabbro.

The most important veins are known as Haugesunds Lode, Daw's Lode, Yorke's Lode, the Hodgkinson Lode, and the Oscar Lode, the last having been the most extensively worked. Operations were commenced here in 1884, and the development has been by means of twelve shafts, varying in depth from 60 feet to 520 feet; three are over 440 feet deep. In the aggregate there have been raised since the date named some 25,000 tons of quartz that have yielded bullion to the value of about £29,250. Quartz and slate traversed by quartz veins, are crushed together, and the yield at present is at the rate of about $7\frac{1}{2}$ dwt. of gold to the ton. In 1893 [1] the production was 1,281 tons of quartz, producing 310 oz. of gold, but at present work is being pushed more energetically. About 90 per cent. of the gold production of Norway comes from this district.

Silver.—The celebrated silver mines of Kongsberg,[2] which were first opened in 1623, are situated in a district consisting chiefly of gneiss, gabbro, mica schist, hornblende schist, talc schist, and chlorite schist. The ore occurs in association with fahlbands, but as these have been already described, pp. 112, 148, no further description of them is necessary. The most remarkable fahl-

[1] *Tabeller Vedkommende Norges Bergværksdrift*, 1896, p. lxxxiii.

[2] *Karsten's Archiv*, xxi. 1847, p. 242; A. Gurlt, *Berg. und Hüttenm. Zeit.* 1858, p. 101; T. Scheerer, *Ibid.* 1866, p. 250; P. Herter, *Zeitschr. d.. d. geol. Gesellsch.* 1871, xxiii. p. 383; G. v. Rath, *Neues Jahrb. f. Mineral.* 1869, p. 434; O. Weltz, *Berg. und Hüttenm. Zeit.* 1878, p. 115.

bands near Kongsberg which occur in Pre-Cambrian[1] slates, are at the Overberg, five miles in length, and about 300 metres in width, on which are some very ancient mines; and on the plateau of Underberg, about 80 metres in width, where some of the workings are 300 fathoms in depth. Several fahlbands occur west of the Overberg. The principal ones being those of Kragsgruben and Barlindalen, and there is a small one at Helgevand. The only mines now working are on the two first-named. The origin of these is explained by Kjerulf and Dahll on the hypothesis of the formation of fissures through tbe eruption of gabbro, and the impregnation of the rocks by metallic sulphides.

At Kongsberg there is a marked distinction between fahlbands in slate and those in gabbro, often spoken of as *Fahler*, the former only been important. The maximum amount of impregnation occurs in mica schists, and the minimum in quartzite slates. Böbert, who was the first to recognise fahlbands as a distinct form, of ore deposit, shows their transition into the lenticular ore beds characteristic of crystalline schists. The Kongsberg fahlbands are comparatively poor, and contain, quite subordinately, compact ore masses which are never worth working. To the miner, however, they are of great importance, since the silver lodes are only productive of ore within the fahlbands. According to Münster[2] there are four types of veins :—

I. Silver bearing veins, the gangue being chiefly calc spar, with smaller quantities of quartz, zinc blende and galena.

II. Felspathic veins younger than I.

III. Quartz veins carrying copper ores, older than I and II.

IV. Quartz veins with a little iron pyrites and calc spar.

The first only are important, and contain silver ore of various kinds, of which silver amalgam is perhaps the most interesting.

Near the town of Kongsberg there are about fifty old mines, of which, approximately, one quarter may have been sunk to a depth of 130 fathoms, the others being generally much shallower. All these mines were formerly worked for silver, and some of them are still working for that metal, which occurs partly as native silver, and partly in the form of various sulphides. The Kongsberg silver mines are the property of the State, those now in operation being the Kongens and Armen Mines, the Gottes Hulfe, and the Haus Sachsen, all in the district of Overberg, the only one in which

[1] Chr. A. Münster, *Kongsberg ertsdistrikt.* 1894, p. 32.

[2] *Op. cit.* p. 42.

work is still extensively carried on. The latter mine after lying unworked for many years, was re-opened in 1866. The Kongens and Armen Mines yielded for a long period the chief portion of the silver produced in Norway, and has, at the deepest point, now reached a depth of 650 metres or 355 fathoms, of which 180 fathoms are beneath the adit level. The Gottes Hülfe is 131 fathoms in depth, and of the material brought to the surface about 60 per cent. is classified as pay rock.

From the Kongens and Armen Mines the average annual production during the five years from 1871 to 1875 was 4,446 cubic yards of rough ore, which yielded about 3,679 oz. troy of native silver, 141 tonnes of rich ore, and 1,468 tonnes of poor ore. From 1865 to 1885 there were excavated 795,000 cubic metres of rough ore, which yielded about 79,500 kilograms of silver.[1]

At the Gottes Hülfe Mine the average annual production during the same period was 1,715 cubic yards of rough ore, affording 835 oz. of metallic silver, 14 tonnes of rich ore, and 511½ tonnes of poor ore. The native silver averaged 880 fine, the percentage of silver in the rich ore being 1·85, and in the poor ore 0·054. From 1865 to 1885 the Gottes Hülfe Mine produced 31,300 cubic metres of rough ore, containing 9,100 kilograms of silver, and the Haus Sachsen Mine 12,800 cubic metres, yielding 5,350 kilograms of silver from 1869 to 1885.[2] During the year 1879 the Kongsberg silver mines yielded the following returns :—[3]

The Kongens and Armen Mines produced 2,577 kilogr. of native silver containing 88 per cent. silver, and 670 tonnes of silver ore containing 0·28 per cent. silver, worth, respectively, 309,200 kroner, or £17,177, and 248,100 kroner, or £13,783.

The Gottes Hülfe Mine produced 81 kilogr. native silver, and 44,374 tonnes of silver ore, worth, respectively, £544 and £944.

The Haus Sachsen Mine produced 37 kilogr. native silver and 52·264 tonnes of silver ore, worth, respectively, £245 and £1,528. This gives a total for Kongsberg of 770 tonnes, worth £34,222. In 1888 the production was 5,960 kilogr. of silver.

In 1879 the only other mine in Norway producing silver was the Svenningdals[4] Mine in Vefsen. This produced 105 tonnes of silver ore containing about 1 per cent. of silver, worth £6,111.

In 1893[5] the total production of the Kongsberg district was

[1] Münster, *op. cit.* p. 46.

[2] Munster, *op. cit.* p. 47.

[3] *Tabeller Vedkommende Norges Bergværksdrift*, 1882, p. 16.

[4] *Ibid.*

[5] *Tabeller Vedkommende Norges Bergværksdrift*, 1896, p. 18.

648 tonnes of silver and dressed silver ores valued at £21,150. The production of the leading Kongsberg mines was as follows:—

	Metallic Silver. Kilogr.	Dressed Silver Ore. Kilogr.
Kongens and Armens Mine . . .	2,635	418,164
Gottes Hülfe Mine	1,090	166,997
Haus Sachsen Mine	186	59,378
	3,791	644,539

The only other mines producing silver in this year were the Jakob Knudsens mines in Tromsø, which produced 242 tonnes of silver ores. These ores were all treated at the Kongsberg smelting works, the total production being 4,773 kilograms of fine silver.[1]

Copper.—The ore masses of Røros and Dovre, near Trondhjem,[2] which are enclosed in Lower Cambrian mica schists, chloritic schists, and clay slates, are always conformable with the strata, and never occur as true veins. The mineralogical character of these deposits is simple, the principal ores being iron pyrites, copper pyrites, magnetic pyrites, and sometimes, at the outcrop, magnetite. Blende and galena are occasionally met with, but otherwise the beds and the slates in which they occur are poor in mineral. The beds may be divided into two classes, the first containing iron pyrites and the second copper pyrites and magnetic pyrites. Copper pyrites is intimately mixed with the iron pyrites, but the mixture of copper and magnetic pyrites is always distinct. The iron pyrites crystallises in cubes, and contains as much as 5 per cent. of copper; in the copper pyrites and magnetite beds this percentage is somewhat greater, while in the Storvarts Mine, at Røros the copper reaches 7 per cent. The magnetic pyrites contains 0·2 per cent. of nickel and cobalt, and the iron pyrites 0·25 per cent. of these metals.

The following analysis[3] shows the percentage composition of the ore, only the more important constituents being, however, determined:

Sulphur	45·00
Iron	37·90
Copper	2·07
Lead	0·38
Zinc	6·42
Silver	4·60
Alumina	2·01
	98·38

[1] *Tabeller Vedkommende Norges Bergværksdrift*, p. 14.

[2] A. Helland, "*Forekomster af kise i visse skifere i Norge*," Christiania, 1873.

[3] J. H. L. Vogt on "Pyrites Deposits in Norway," &c., *Zeitsch. f. Prakt. Geol.* 1894, p. 41.

The beds, although always conformable, are extremely irregular, so that they sometimes represent short masses, with but little extension either in the direction of their strike or dip. Their thickness is variable, the thickest mass of pyrites being probably that in the almost abandoned mine of Løkkens, namely eighty-five feet. Thicknesses of from thirty-three to forty-two feet are sometimes found at Ytterøen, Foldal, and Undal, but this great width is exceptional, the average not being above from three to eighteen inches. At Foldal the deposit is 220 metres in length and from 2·5 to 14 metres in width; at Storvarts it is 1,350 metres in length by 200 metres wide, and from 1 to 3 metres in thickness; Vigsnaës has attained a depth of about 735 metres. The Røros beds, which are nearly horizontal, have been followed in the direction of their dip for about 710 fathoms. The pyrites beds usually disappear by thinning out, but they sometimes become divided before disappearing. These beds are found in certain slates only, and are absent in all the other formations. In the province of Trondhjem, in Søndfjord and in Sondhørdland, there are non-fossiliferous slates which are remarkably rich in pyrites. This pyritiferous formation frequently lies immediately above the Azoic rocks.

In the large pyrites deposits at Ytterøen slate seams alternate with pyrites; and in the middle of the pyrites bed at Undal there is a stratum of alum slate, with a strike and dip coinciding with that of the pyrites. It is remarkable that some of the beds containing pyrites are of a black colour, from being mixed with a certain proportion of carbon; thus the pyrites from Stordøen contains 2·6 per cent. of that substance. It is well known that pyrites sometimes replaces organic forms, so that these beds may possibly have been deposited through the instrumentality of organisms.

The yield of Røros during the year 1879 was as follows:—

The Storvarts Mine produced 2,380 tonnes of copper ore, containing 7 per cent. of copper; the Ny-Solskin Mine 380 tonnes, containing 6·3 to 8 per cent. of copper; the Kongens and Arvedals Mines 1,920 tonnes, containing from 3·2 to 3·6 per cent. of copper; and the Gammel-Solskin Mine 510 tonnes copper ore; giving a total for the Røros district of 6,880 tonnes copper ore, worth £17,770 and 4,550 tonnes cupriferous iron pyrites, containing 43 per cent. sulphur, worth £3,185.[1] The Røros district produced in 1893[2] a total of 2,416 tonnes of pyrites and 10,449 tonnes

[1] *Tabeller Vedkommende Norges Bergværksdrift*, 1882, p. 19.

[2] *Ibid.* 1896, p. 11.

of copper ore; of the latter total 2,756 tonnes, averaging between 5·87 and 6·45 per cent. of copper, were contributed by the Storvarts Mine, and 3,309 tonnes, averaging from 4·10 to 4·64 per cent. of copper, were produced by the Kongens Mine.

The Varaldsö Mine (see p. 183), which is worked upon a bedded vein enclosed in the slates of the island of the same name, has, during the last sixteen years, afforded an average yield of 9,000 tons of pyrites annually. This ore contains less than 1 per cent. of copper, but is almost entirely free from arsenic.

The Ytterø Mine, in Ytterøen, produced, in 1879, 409 tonnes cupriferous iron pyrites, and 6 tonnes of copper ore, worth £315. In 1893 the production was 21,697 tonnes of pyrites, containing 1 to 3 per cent. of copper and 45 to 46 per cent. of sulphur, and 17 tonnes of copper ore.

In 1879 the Vigsnæs Mine, near Stavanger, produced 39,898 tonnes of cupriferous iron pyrites, worth £69,500. Vogt (*loc. cit.*) considers these ores as having been formed in zones of crushing and shearing, produced by the excessive folding of the strata; the introduction of the metallic constituents being connected with the intrusion of the Saussurite gabbros, which accompany all these Norwegian pyrites deposits.

In 1893 the Stavanger Mines produced 21,824 tonnes of cupriferous iron pyrites of a character similar to that of Ytterø.

The ore district of Telemarken begins two geographical miles from Kongsberg, and extends sixty-five miles to the west and south-west, and forty-eight miles to the north, of that town.

The rocks of the district consist of quartzites, quartzite slates, hornblende schists, &c., and these are penetrated by granite and are traversed by granitic veins; in some places these granite veins contain copper ores. Scheerer [1] describes granite veins at Strömsheien on a table-land about 3,300 feet above the sea, between Moland, in Telemarken, and Valle, in Sädersdalen, which, although occurring in gneiss, have the greatest similarity to the veins in the slates of Telemarken.

These granite veins, which are of variable thickness, namely from 16 to 25 feet, consist of a granite very rich in quartz but poor in mica, containing, as accessories, magnetite, garnet, apatite, beryl, and various other minerals. They contain copper glance in nests and ramifications, in such a way that Scheerer was led to suppose that the ore and granite were introduced at the same time by igneous fusion. The copper ores enclosed within the

[1] *Berg. und Hüttenm. Zeit.* 1863, p. 157.

granite of Telemarken are mixed with quartz, and of this he describes two characteristic examples, namely: a vein at the Moberg Mine, from three to thirteen feet in thickness, and almost vertical, consisting half of granite and half of quartz, containing copper ores, with tellurium-bismuth; and a thick granite vein at the Näsmark Mine, traversed by regular vein fissures running obliquely across it, filled with quartz, copper glance, and variegated copper ore.

Fig. 101, after Scheerer, is a section of this vein, in which *a* represents mica schist, *b* granite, and *c* veins of quartz containing copper ores.

Herter[1] thinks it certain that the quartz and copper ores were subsequently deposited in fissures in the granite vein, and there can be but little doubt that the copper ores and quartz filling

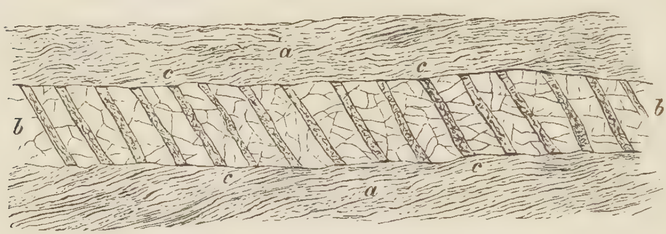


Fig. 101.—Vein at the Näsmark Mine; horizontal section.

these fissures are the result of segregation from the granite or else of a leaching action, in the same way that the gold quartz of the Australian *mullock veins* is the result of the decomposition of an eruptive rock. With an increase of depth all the copper lodes of Telemarken have gradually become less valuable. In 1893 the production of various small Telemarken mines was 1,024 tonnes of ore assaying 20 per cent. of copper.

A thick mass of diorite, coursing from north to south, continuous for many miles, and traversing both crystalline slates and grauwacke, contains at Kaafjord, in latitude 69° north, various copper lodes. These course from south-west to north-east, are from one foot to fourteen feet in thickness, and are filled with a breccia of quartz, calc spar, iron pyrites and copper pyrites, which are cemented together by altered diorite.

The Kaafjord Mine produced, in 1878, 2,700 tonnes of copper ore, worth £6,555, and employed fifty-five men. 1879 this mine

[1] *Zeitschr. d. d. geol. Gesellsch.* vol. xxiii. 1871, p. 377.

was not working.[1] In 1893 there were smelted in Norway 16,326 tonnes of copper ore, almost exclusively at Røros, with the production of 786 tonnes of metallic copper. The cupriferous pyrites is all, however, exported as such, and not treated in the country.

Nickel.[2]—The nickel deposits of Ringerikes occur in fahlbands or in belts of micaceous and hornblendic schists, impregnated with nickel-bearing pyrrhotine in the neighbourhood of certain gabbro dykes. Their production in 1876 was 9,320 tonnes of nickel ore, containing 1·5 per cent. of nickel, worth 375,000 kroner, or £20,833. In 1879 it only amounted to 420 tonnes, worth £777. In 1893 the Ringerikes mines were not producers, but in 1892 their output was 3,582 tonnes of ore containing 1·8 per cent. of nickel. Two other mines produced nickel ore in 1879, namely: Bamble, 300 tonnes, worth £770; and the Senjen Mine, 3,828 tonnes, worth £5,000.

A nickel mine, formerly of great importance, is that of Espedalen, near the town of Lillehammer. The district is composed of gabbro and amphibolite, both possessing a gneissic structure and containing, in fahlband-like zones, nickeliferous magnetic pyrites yielding from 2 to 3 per cent. of nickel, with nickeliferous iron pyrites containing about 2·1 per cent. of nickel with a little copper.

The production in 1876 was 2,250 tonnes of nickel ore, worth £4,722, but since that year no ores have been raised at this mine.

The production of nickel ores in Norway has of late years fallen off considerably; in 1876 the total yield was 42,550 tonnes, containing 332 tonnes of metallic nickel, worth £143,333; in 1879 it was only 4,548 tonnes, containing 46 tonnes of metallic nickel, value £15,861. In 1893 [3] it was only 2,397 tonnes, worth only £1,320, all produced from the Eoje mines. In that year, however, there were 6,500 tonnes of ore smelted, equivalent to 113 tonnes of metallic nickel.

Cobalt.—The cobaltiferous fahlbands of the district lying around Skutterud and Snarum, occur in crystalline rocks varying in character between gneiss and mica schist, but, from the presence of hornblende, they sometimes pass into hornblende schists; among the accessory minerals are garnet, tourmaline, and graphite. These schists, of which the strike is north and south, and which have an

[1] *Tabeller Vedkommende Norges Bergværksdrift*, 1882, p. 19.
[2] T. Scheerer, *Berg. und Hüttenm. Zeit.* 1845, p. 801.
[3] *Tabeller Vedkommende Norges Bergværksdrift*, 1896, p. 11.

almost perpendicular dip, contain fahlbands very similar in character to those of Kongsberg. They differ from those of that locality, however, inasmuch as while here the fahlbands are often sufficiently impregnated with ore to pay for working, those of Kongsberg, although to some extent containing disseminated sulphides, are only of importance as zones of enrichment for ores occurring in veins. The ore zones usually follow the strike and dip of the surrounding rocks, and vary in breadth from 2½ to 6 fathoms. The distribution of the ores is by no means equal, since richer and poorer layers have received special names and are easily recognised. The *Erzbänder*, or ore bands, are distinguished from the *Reicherzbänder*, or rich ore bands; while the bands of unproductive rock are known as *Felsbänder*. The predominant rock of the fahlbands is a quartzose granular mica schist, which gradually passes into quartzite, ordinary mica schist or gneiss. The ores worked are cobalt glance, arsenical and ordinary pyrites containing cobalt, skutterudite, magnetic iron pyrites, copper pyrites, molybdenite, and galena. It is remarkable that in these mines nickel ores do not accompany the ores of cobalt in any appreciable quantity. The principal fahlband is known to extend for a distance of about six miles, and is bounded on the east by a mass of diorite which protrudes into the fahlband, while extending from the diorite are small dykes or branches traversing it in a zigzag course. It is also intersected by dykes of coarse-grained granite which contain no ore, but which penetrate the diorite.

The Skutterud Mine in 1879 produced 7,700 tonnes of cobalt ore, which yielded 108 tonnes of cobalt schlich, containing from 10 to 11 per cent. of cobalt, and worth about £11,000. In 1888, 5,540 tonnes of raw ore were produced, and 3,456 tonnes in 1890. In 1893 the production was 123 tonnes of dressed ore, worth £2,472, thus showing a marked falling off in the productiveness of these deposits.

Iron.—The rocks in the vicinity of Arendal[1] are gneiss and various crystalline schists, which enclose beds of limestone, and often pass over into mica schist or hornblende schist. These rocks strike north-east and south-west, dip at a considerable angle south-west, and enclose numerous deposits of magnetite more or less mixed with specular iron ore, in a belt sixteen miles in length, parallel with the coast, and extending from Oyestad to Flackstad.

[1] T. Kjerulf and Tellef Dahll. *Neues Jahrb. f. Min.* 1862, pp. 557–581.

The ore masses are of a lenticular form, vary from 6 to 60 feet in thickness and from 250 to 600 feet in length, and are surrounded by a peculiar envelope, consisting of a mixture of the constituents of the metalliferous bed and of the country rock, the principal minerals being mica, hornblende, epidote, garnet, calcite and magnetite. The centre of the bed usually consists of magnetite, which is sometimes coarsely granular, but is always accompanied by augite, hornblende, garnet, calcite, and the constituents of gneiss, as well as by various other minerals. These, when crystallised, have rounded faces, a peculiarity frequent with crystals formed in granular limestone. A somewhat foliated texture parallel to that of the enclosing rock, and representing the longitudinal extension of the lenticular masses, is often to be remarked. A great variety of minerals is found in the fissures which traverse the ore bed; among these may be mentioned stilbite, datolite, prehnite, fluor spar, &c. Granitic veins, containing many rare minerals, traverse equally the ore bed and the country rock. The different beds have very different forms, and do not all contain the same minerals, so that each exhibits distinct individual peculiarities.

Haussmann states that these deposits, as well as the enclosing rocks, are traversed by three distinct vein formations, namely: by veins whose composition is similar to that of the ore deposit; by veins composed of felspar and calc spar, containing titanite; and, lastly, by veins of coarsely granular granite.

No returns were made for Arendal in 1879, and in that year the production of iron ore in Norway was confined to the Naes and Egelands Mines, and the Fensgruberne in Holden, producing, respectively, 2,400 tonnes and 5,660 tonnes of iron ore, worth £1,055 and £2,500 and employing in the aggregate thirty-eight miners.

The production of iron ores has now fallen to quite insignificant dimensions, competition with the rich and abundant Swedish deposits being apparently impossible. The only mine that produced any ore in 1893 was that of Klodeberg, with an output of 800 tonnes. Vogt[1] has described a number of extensive deposits of iron ores in Dunderlandsdal, Nissedal and other places, which appear only to await an economical means of transport to become important sources of iron production.

[1] J. H. L. Vogt, "Dunderlandsdalen jernmalmfelt," *Norges Geologiske Undersögelse*, No. 15; "Nissedalens jernmalmforekomst," *Ibid.* No. 17; "Om dannelse af jernmalmforekomster," *Ibid.*

General Summary of the Production of Metalliferous Minerals in Norway during the Years 1879 and 1893.

1879.[1]

Description of Ore.	Quantities.	Values.	
	Tonnes.	Kroner.	£
Silver ore	875	726,000	40,334
Iron ore	8,060	64,000	3,556
Copper ore	10,469	640,000	35,556
Cupriferous iron pyrites	50,318	1,395,700	77,539
Nickel ore	4,548	118,000	6,556
Cobalt ore	108	200,000	11,112
Zinc and lead ore	9	300	17
Total value of Metalliferous minerals produced in 1879		3,144,000	£174,670

1893.[2]

Description of Ore.	Quantities.	Values.[3]	
	Tonnes.	Kroner.	£
Cobalt ore (dressed)	123	45,000	2,472
Copper ore	21,907	648,900	35,654
Gold	0·01043	22,000	1,209
Iron ore	800	5,500	302
Iron pyrites (in part cupreous)	53,754	704,000	38,681
Nickel ore	2,397	24,000	1,319
Silver and silver ore	890	433,500	23,819
Rutile	7	6,000	330
Total value of Metalliferous minerals produced in 1893		1,888,900	£103,786

Sweden.

A large portion of the surface of Sweden is composed of crystalline rocks, such as granite, gneiss, porphyry, &c., and in these the most important metalliferous deposits have been discovered. The crystalline Primary rocks are, generally speaking, immediately covered by beds of Quarternary age, and a very small portion only of the intermediate formations is represented. Of these, rocks of Silurian age occupy the largest area.[4]

[1] From *Tabeller Vedkommende Norges Bergværksdrift*, Christiania, 1882.

[2] *Ibid.* 1896, p. 2.

[3] Exchange taken at 18·2 kroner = £1.

[4] See also *L'Industrie Minière de la Suède*, by Prof. G. Nordenström, 1883.

Gold.—No true gold mines exist in Sweden, but a good deal of gold is obtained from the Falun copper mines, some parts of which are auriferous and occasionally show free gold. The whole of the gold production for 1894,[1] which amounted to 93·6 kilogr., was from this source with the exception of about 13 kilogr. obtained from the Kafveltorp lead-works. The gold production of Sweden was only about 5 kilogr. annually from 1870 to 1880, when it commenced to rise, and has averaged a little over 90 kilogr. since 1890.

Lead and Silver.—The argentiferous lead ores of Sala in Vestmanland occur in irregular veins, coursing through granular limestone, and are more or less mixed with such minerals as calcite, chlorite, talc, sahlite, epidote and actinolite. They are also associated with layers of hälleflinta and serpentine, while quartz, heavy spar, and some other minerals are occasionally present. The galena is usually accompanied by other metallic sulphides, such as iron pyrites, magnetic pyrites, blende, geocronite, boulangerite, and, more rarely, with stibnite, mispickel, &c. The silver usually occurs as sulphide in the form of argentiferous galena, and but rarely either in the native state or in combination with other metallic elements, although specimens of native amalgam are known to have been found at Sala about two hundred years ago. As the deposits are not separated from the enclosing rocks by well-defined walls, the ores are often disseminated through the surrounding limestone, or infiltrated into its fissures to a distance of several fathoms from the more concentrated masses. This sometimes takes place at one side, and sometimes on the other, but occasionally on both sides of the vein. The disseminated ore gradually decreases in quantity as a greater distance from the main deposit is reached, until it at length becomes too poor for working, and gradually passes into a pure limestone entirely destitute of ore. According to De Launay[2] these deposits are not veins, but form a series of irregular masses in a bed of dolomite, although lying between two vertical walls and thus resembling veins; the dolomites are traversed by fault fissures known as *skölar*, which are filled with a brecciated mass of rocks derived chiefly from their own walls, together with a number of other minerals, some of which are metalliferous, so much so that these fissures have been compared to the fahlbands of Kongsberg. The line of mineral deposits follows the course of the fissures, the main

[1] *Bidrag till Sveriges Officiela Statistik (Bergshandteringen) för år* 1894, p. xiii.

[2] Fuchs and De Launay, *Traité des gîtes minéraux et métallifères*, ii. p. 613.

direction being about N.N.E.—S.S.W. The ore as mined contains about 25 per cent. of galena rich in silver, the work lead carrying 0·7 per cent. It would seem that these deposits, like so many silver deposits in calcareous rocks, are the result of the metasomatic action of mineralising solutions, which penetrated the rock along the line of fracture where it was readily permeable to them. The old mine of Sala is remarkable as having been wrought to the depth of 165 fathoms almost entirely without the use of gunpowder, the primitive method of fire-setting being continued to recent times.

Similar deposits are found at Löfas in Dalecarlia, and Guldmedshyttan in Vestmanland, where lead ores occur in granular limestones belonging to the crystalline slates. The production of lead and silver ore at Sala during the ten years from 1870 to 1879 inclusive was 83,853 tonnes, or an average of 8,385 tonnes per annum.[1] In 1894[2] this mine produced 7,316 tonnes of crude ore; these gave 5,014 tonnes of argentiferous lead ores, which yielded on smelting 280 tonnes of lead, 2,506 kilogr. of bar silver and 2,184 kilogr. of silver precipitate containing 7·84 per cent. of metal, this forming the bulk of the silver production of Sweden.

The Löfas Mine, which is fifty fathoms in depth, produced from 1870 to 1879, 729 tonnes of silver lead ore, giving an annual average of 73 tonnes. It does not appear on the list of producers for the year 1894.

Zinc.—The most important zinc mine in Sweden is that of Åmmeberg,[3] which lies between the great lakes Wener and Wetter, and belongs to the famous Belgian company La Vieille Montagne. Here a remarkable deposit of blende occurs in banded gneiss (*hälleflinta*), close to the contact of this rock with granite, forming a belt 250 fathoms in thickness, which can be followed for a distance of nearly two miles along its strike. This zone is composed of a gneiss, consisting of a mixture of gray felspar and quartz, with but little mica. All the metamorphic rocks of the district are also traversed by eruptive diorites, with the existence of which that of the ore deposits is perhaps genetically connected. The deposit of blende has a very varying thickness, dips at angles of from 70° to 80°, and consists of a number of lenticular masses which sometimes

[1] *Jernkontorets Annaler*, 1883, p. 32.

[2] *Bidrag till Sveriges Officiela Statistik* (*Bergshandterigen*) *för år* 1894, pp. 11, 13.

[3] F. M. Stapff, *Berg. und Hüttenm. Zeit.* 1861, p. 252; B. Turley, *Ibid.* 1866, p. 405.

attain a thickness exceeding twelve fathoms. In many places blende can be seen to replace the mica of the gneiss, but geodes of ore never occur in these deposits. The blende, which is black to yellowish in colour, is rarely accompanied by galena, but more frequently by iron pyrites and magnetic pyrites. The other minerals found with the zinc ore are amazonstone, hornblende, talc, chlorite, garnet, black tourmaline and bitumen; calc spar is rare, and neither magnetite, magnetic pyrites, nor iron pyrites beds accompany the blende.

The present depth of this mine is 58 fathoms, and, during the period 1870 to 1879 inclusive, it produced 341,524 tonnes of zinc ore and 14,439 tonnes of argentiferous galena; an average, respectively, of 34,152 tonnes of zinc ore, and 1,444 tonnes of lead ore, per annum.[1] In 1894 [2] the total amount of ore raised amounted to 54,563 tonnes, which yielded 42,912 tonnes of zinc ore and 536 tonnes of galena. The above forms the bulk of the zinc production of Sweden, which averaged 47,000 tonnes in 1893 and 1894, having been nearly 62,000 tonnes in 1890.

Copper.—The well-known copper ore deposit of Falun [3] has been worked from a very remote period, originally as an open cast, and is in many respects comparable with the huge pyrites deposits of Huelva; according to some authorities it is probably to be regarded as a bedded deposit. The ores are associated with a massive stratum of a gray splintery quartz, which is enclosed in mica schist rich in quartz; the schist is interstratified in the gneiss. In the quartz bed small quantities of the alkalies and a little alumina have been found, and it has therefore been sometimes regarded as a variety of hälleflinta.

The so-called concretions form lenticular masses generally running parallel to the stratification, and in a bed which contains enclosures of magnetite and pyrites, there are lenticular masses of ore, sometimes attaining a thickness of above thirty feet, and continuing for a distance of 100 feet along their line of strike. These masses consist principally of iron pyrites, magnetic pyrites and copper pyrites. Thin laminæ of chlorite and quartz are frequently enclosed in the mass, but blende and galena are somewhat rare. The ore masses have no well-defined boundaries, but pass over gradually into the country rock. The quartz

[1] *Jernkontorets Annaler*, 1883, p. 32.

[2] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, pp. 10, xii.

[3] F. M. Stapff, *Berg. und Hüttenm. Zeit.* 1861, p. 195.

bed is intersected in various directions by irregular bands of talcose or chloritic rocks, which the miners call *skölar;* these enclose fine crystals of magnetite, gahnite, garnet, falunite, &c. Irregular pyritic lenticules are enclosed in the *skölar*, their principal mass consisting of finely granular iron pyrites and copper pyrites with in places, blende and galena. Besides ore and *skölar* the quartz bed contains diabase and limestone. *Hårdmalm* (hard ore) is the name given by the Falun miners to the ore consisting of pyrites with quartz; it is the richest in copper and the purest variety of ore. Where the country rock is impregnated with ore the mineral from such impregnations bears the name *tvikmalm* (doubtful ore), because from mere inspection the miners are unable to determine whether it can be worked at a profit. Ores consisting of pure pyrites are termed *blötmalm* (soft ore), and are very similar to those of the Rammelsberg, but are generally more crystalline. *Segmalm* (tough ore) is a mixture of pyrites with talc, chlorite and black mica. The proportion of copper in the pyrites treated varies from 1 to 2 per cent., and in the "hard ore" from 3 to 4 per cent. Professor Eggertz found traces of gold in the Falun copper, but was unable to discover from which particular variety of ore it was derived. This mine, which is 194 fathoms in depth, yielded, during the ten years immediately preceding 1880, an average of 24,438 tonnes of cupriferous pyrites and 1,181 tonnes of iron pyrites annually.[1]

According to Vogt,[2] it has produced 1,200,000 tonnes of copper. equal to 35–40 millions of tonnes of ore, since the year 1200 and now produces annually about 500 tonnes of copper, 400 kilogr. of silver, and 80 to 100 kilogr. of gold. The latter occurs chiefly in veins of quartz in the *Härdmalm* in a working known as Minkas. This deposit, like the majority of those of Scandinavia, would appear to be connected genetically with certain igneous rocks (gabbro, diorite and diabase) that traverse the metamorphic strata in its vicinity. In this respect it presents marked analogies with the deposits at Huelva, and other similar masses of pyritic ore. Its production in 1894[3] was 15,734 tonnes of copper ore and 629 tonnes of iron pyrites. The copper ore yielded 164 tonnes of refined copper, and 255 kilogr. of silver, besides the gold already mentioned.

[1] *Jernkontorets Annaler*, 1883, p. 30.

[2] *Zeitsch, f. Prakt. Geologie*, 1894, p. 41.

[3] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, pp. 12, 13.

At Tunaberg the ore occurs in a bed of granular limestone in gray gneiss. The limestone contains, principally, hornblende, mica, serpentine, lead, silver, copper and cobalt ores, copper pyrites and cobalt glance being the most frequent.

This mine is 98 fathoms in depth, and during the ten years 1871 to 1880 has annually produced about 286 tonnes of copper ore.[1]

The fahlbands of Åreskuttan, in Jämtland, are wrought for copper pyrites. The Loos Mine, on the road from Falun to Åreskuttan, is worked on masses of amphibolite, which are enclosed in mica schists and quartz beds. The amphibolite contains enclosures of erubescite, copper pyrites, iron pyrites, blende, speiss cobalt, cobalt pyrites, nickel glance, quartz, calc spar and anorthite.

These two last-named mines do not figure amongst the list of producers for 1894; at that time the only other important copper mines were the Bersbo Mine at Åtvidaberg and Kafveltorp,[2] both of which are worked on deposits somewhat resembling those at Fahlun. The former has been followed down to a greater depth than any other in Sweden; its production in 1894 was 8,126 tonnes of copper ore which yielded 133 tonnes of refined copper, together with 284 kilogr. of silver precipitate, containing 39 per cent. of metal. The latter mine, which also produces a considerable quantity of argentiferous galena, produced in the same year 756 tonnes of copper ore, which yielded 53 tonnes of metal.

Iron.—At Dannemora, in Upland, north of Upsala, coarsely foliated gneiss encloses a broad zone of hälleflinta with chloritic schist, granular limestone, and interstratified beds of magnetic iron ore. The latter have the characteristic lenticular shape, and form a huge deposit, which has been worked along the outcrop for a distance of more than a mile. This deposit is in the middle above 180 feet in thickness, but gradually decreases on both sides. The ore, which contains manganese, is a very finely granular magnetite, mixed with particles of chlorite, together with a little calc spar and brown spar. Bands of chloritic slate, *skölar*, up to twelve feet in thickness, traverse the ore deposits. The purest magnetite occupies the middle of the deposit, while near the edges iron pyrites, copper pyrites, blende, galena, arsenical pyrites, quartz, garnet, asbestos, heavy spar, anthracite, &c., occur.

The mode of formation of this deposit is doubtful; it may have been a true bed of spathic ore or hæmatite, deposited as such,

[1] *Jernkontorets Annaler*, 1883, p. 32.
[2] *Ibid.* pp. 10, 13.

or formed epactically, and subsequently metamorphosed into magnetite, along with the country rocks, or it may be a bedded vein, whose origin is connected with that of the eruptive rocks of the district. Löfstrand (quoted by Vogt [1]) looks upon this and similar deposits as having been formed by magmatic segregation from acid eruptive rocks, although Vogt himself does not share this view.

This mine is 110 fathoms in depth, and during the ten years 1871 to 1880 has annually produced about 35,300 tonnes of iron ore. [2]

In 1894, [3] the mines of the Dannemora district produced 51,631 tonnes out of a total of 62,971 tonnes raised in the province of Upsala.

At Taberg, near Jönköping in Småland, the mountain rises about 400 feet above the surrounding gneiss. Opinions have considerably differed with regard to the character of this deposit, but A. Sjögren,[4] who has examined a number or sections under the microscope, finds that the entire mountain consists of a granular crystalline mixture of magnetite and olivine with some plagioclase, mica, and apatite, as accessory constituents; but pyroxene and hornblende are entirely absent. The olivine is very fresh, being only exceptionally serpentinised.

The average annual production of iron ore at Taberg during the ten years 1871 to 1880 was about 8,250 tonnes. In 1894 [5] it had fallen to 3,700 tonnes.

The beds worked in Vermland in the neighbourhoods of Philippstadt, Nordmark, Långbanhytta, Pajsberg, &c., are very rich in ore. The beds of Pajsberg are enclosed in crystalline granular dolomites from 20 to 100 fathoms in thickness; these dolomites contain granular concretions of hausmannite.[6] The beds, which are from 6 to 18 feet in thickness and are continuous for about thirty fathoms along their strike, consist of magnetite, specular iron ore and hausmannite, together with pyrochroite, tephroite, chondroarsenite, heavy spar, diallogite, asphaltum, garnet, chlorite, serpentine, &c. The province of Vermland [7] produced 79,055

[1] J. H. L. Vogt, "Beiträge zur genetischen classification der durch Magmatische Differentiations-processe u. durch Pneumatolyse entstandenen Erzvorkommen," *Zeitsch f. Prakt. Geol.* 1894, p. 381.

[2] *Jernkontorets Annaler*, 1883, p. 32.

[3] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, p. 3.

[4] *Jahrb. f. Min.* 1876, p. 434.

[5] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, p. 3.

[6] L. J. Igelström, *Berg. und Hüttenm. Zeit.* 1866, p. 21.

[7] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, p. 3.

tonnes of magnetite and 4,175 tonnes of specular ore in 1894.

The island of Utö, a few miles south of Stockholm, consists largely of a highly felspathic gneiss, which is traversed by numerous veins of granite. The iron ore deposit, which is embedded in the gneiss and its associated mica slates, hornblende slates, hälleflintas, and granular limestones, is sometimes as much as 125 feet in thickness, and consists of a mixture of specular iron ore, magnetic iron ore and quartz. These minerals are accompanied by iron pyrites, magnetic pyrites, arsenical pyrites, galena and chalcocite, together with native silver. Granitic veins, containing cassiterite with tourmaline, lepidolite, petalite, &c., traverse the bed, in the fissures of which crystals of calc spar, apophyllite, and quartz are found. The depth of the workings is 120 fathoms, and the average annual output of iron ore was about 10,300 tonnes in the decade 1870 to 1879.

The iron ore deposits of the montain of Gellivara,[1] in Lulea-Lappmark, are exceedingly rich, but on account of their geographical position, latitude 67° 20′ N., have only recently—since about 1892—attained to any practical importance. In 1894 they furnished more than a third of the entire production of Sweden.

The beds attain a thickness varying from 60 to 125 feet, and may be traced for a distance of nearly four miles along their strike. They occur in red gneiss, and consist of a mixture of specular iron ore and magnetite, containing hornblende and quartz; more rarely apatite, calc spar, and corundum.[2] The ores are of two grades, nonphosphoric and phosphoric, the latter due to an admixture of apatite. They are said by Swedish engineers to occur as lodes in metamorphic rocks. It is chiefly due to the opening up of these mines that the exports of Swedish iron ore rose from 174,148 tons in 1891 to 447,931 tons in 1893. In 1894[3] Gellivara produced 655,401 tonnes of mangnatite, almost entirely from open workings.

Lake ores[4] are found in many of the Scandinavian lakes, most frequently in Småland, Southern Oestergötland, North-western Dalarne, in Herjeådalen, in parts of Jämtland, in the whole of

[1] *Jernkontorets Annaler*, 1883, p. 32; B. Turley, *Berg. und Hüttenm. Zeit.* 1863, p. 348.

[2] J. Head, "Scandinavia as a source of iron ore supply," *Journ. Iron and Steel Inst.* 1894, i. p. 52.

[3] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, p. 7.

[4] F. M. Stapff, *Zeit. d. d. geol. Gesellsch*, xviii. 1866, p. 86.

Norrland, and more rarely in Helsingland, Gästrikland, Southern Dalarne, and Vermland. In some provinces, however, as in Upland, Södermanland, Westergötland, &c., they are entirely absent. Abundance of fuel and the absence of other ore is the chief reason why in some provinces these ores have been better investigated and more extensively worked than in others. The districts richest in such ores have a sandy soil, and are more or less covered by forests and peat bogs. Stapff is of opinion that lake iron ore is formed in the same way as bog iron ore (see page 36), and he points out that in the lake of Tisken, near Falun, the water from the mine and from the slag heaps has deposited a bed of ochre extending over the entire bottom of the lake within a period of about 600 years; this bed is in places above ten feet in thickness. Lake ores when first collected are blackish-gray, brownish, or greenish ochre-like slimes; on hardening, however, little globular masses analogous to those of oolitic iron ores are often formed.

The production of these ores fluctuates within wide limits; in 1893 [1] it was 2,275 tonnes, and in 1894 only 689 tonnes, practically the whole of which was obtained in the provinces of Jönköping.

According to G. Nordenström [2] the production of iron ores in Sweden was 84,500 tonnes in 1730, 180,000 in 1800, 254,627 in 1835, 280,180 in 1850, 806,000 in 1881; in the last-named year iron ore was raised in thirteen of the twenty-four provinces. The largest amount was produced in the province of Örebro, whose 362 mines furnished 220,000 tonnes; next came Kopparberg with 181 mines, yielding 210,000 tonnes, and Vestmanland producing 170,000 tonnes from 57 mines.[3]

The following table shows the production by provinces in 1894:—[4]

Province.	No. of Mines.	Iron Ore. Tonnes.
Stockholm	9	19,854
Upsala	21	62,971
Södermanland	11	27,262
Östergötland	1	3,532
Jönköping	3	2,700
Vermland	39	83,230
Örebro	92	298,654
Vestmanland	59	209,562
Kopparberg	75	547,911
Gefleborg	6	12,686
Norrbotten	10	658,161
Totals	326	1,926,523

[1] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, p. viii.

[2] *Journ. Iron and Steel Inst.* 1894, ii. p, 526.

[3] *Iron*, 1883, xxi. p. 414.

[4] *Ibid.* p. 3. (= *Bidrag, etc.*)

To the above figure must be added the 689 tonnes of lake ores, making the total production 1,927,212 tonnes. Of the former total, 85·4 per cent. or 1,644,328 tonnes were magnetite, and 14·6 per cent. or 282,195 tonnes were red hæmatite. It may also be noted that only 1,915,175 tonnes were obtained by mining, the balance, or 11,348 tonnes, having been produced by the dressing of old spoil-heaps.[1]

During ten years, 1870 to 1879, the average annual production of metalliferous minerals in Sweden was as follows:—[2]

	Tonnes.
Iron ore { mine	748,427
Iron ore { lake and bog	8,872
Copper ore	40,638
Zinc ore	34,718
Silver and lead ore	11,010
Nickel ore	4,319
Iron pyrites	1,517
Manganese ore	538
Cobalt ore	153
Total	850,192

The production of ores in 1894 was:—[3]

	Tonnes.
Iron ores	1,927,212
Argentiferous lead ores	14,825
Copper ores	25,710
Zinc ores	47,029
Manganese ore	3,359
Iron pyrites	656

In that year the following amounts of metals were produced in Sweden, all of them from ores raised in the country:—

Pig iron	462,809	tonnes
Wrought iron and steel billets, &c.	373,257	"
Manufactured iron	286,302	"
Copper	350	"
Lead	330	"
Gold	93·6	kilogr.
Silver	2,870	"

[1] Note from Prof. G. Nordenström.

[2] *Jernkontorets Annaler*, 1883, p. 32.

[3] *Bidrag till Sveriges Officiela Statistik* (*Bergshandteringen*) *för år* 1894, pp. 3-13.

THE RUSSIAN EMPIRE.

European Russia consists of an immense expanse of plain flanked by the mountain ranges of the Timan, the Ural, and the Caucasus, almost entirely composed of sedimentary rocks, which are frequently covered by thick alluvial deposits.

Great regularity predominates in the structure of these formations, ore deposits occurring chiefly in areas occupied by the older rocks, as in the district of Olonetz, St. Petersburg, and in the south of Russia. Devonian rocks form a large basin in Central Russia, and in Poland contain deposits of copper. Iron ore occurs in the Carboniferous rocks of Poland, and copper ore is found at various places in rocks of Permian age. The Triassic rocks of Poland are analogous to those of Upper Silesia and, like them, contain deposits of calamine, galena, and iron ore.

The principal metals produced in Russia are gold, platinum, silver, copper, lead, zinc, manganese, and iron; tin, nickel and cobalt also occur in very subordinate quantities. The chief sources of the more valuable metals are the mountain chains of the Ural and the Altai, particularly the former. Copper is found not only in those regions, but also in the Caucasus, in Finland and in the Kirghese region. Iron occurs abundantly in the Ural Mountains, in portions of the Altai, and in some of the southern and central parts of the empire, also in Poland, Finland and the north. The zinc deposits of Poland were about 1880 among the most productive in Europe. Since 1886 the manganese ores of the Caucasus have been one of the world's chief sources of supply.

Mining had not assumed an important position among the industries of Russia until about the year 1700, from which period until the reign of Elizabeth its development progressed very rapidly. Towards the latter half of the last century, however, a depression commenced in this class of industry, which, after extending over several years, has of late shown marked indications of improvement.[1]

Ural Mountains.—From a geological point of view the western and eastern declivities of the Ural chain differ very considerably.

[1] *Aperçu des Richesses Minérales de la Russie d'Europe publié par le Département des Mines du Ministère du Domaine de l'État*, Paris, 1878; C. Skalkowsky, *Tableaux Statisques de l'Industrie des Mines en Russie en* 1868–1876; J. D. Hague, *Mining Industries*, 1878, p. 247.

The western slopes are formed by hills parallel to the principal axis of the chain, gradually lowering towards the plains. These hills are composed of sedimentary rocks in which, especially near the principal axis of the range, are enclosed masses of granite, diabase, and diorite; in proportion as these disappear the beds become less disturbed, and gradually attain exceptional regularity as they approach the lowlands of the west.

The eastern side of the range is entirely different, becoming, at a relatively small distance from the axis, flat and uniform, the mountain sides being formed almost entirely of plutonic rocks enclosing embedded fragments of sedimentary strata. Faults and slides are of frequent occurrence both in the mountains and in the flat country as far as the eruptive rocks extend.

A geological map of the western slope of the Ural exhibits Silurian, Devonian, Carboniferous and Permian rocks, arranged as more or less parallel bands. On the eastern side of the chain the rocks also exhibit parallel bands, but they are very much contorted and confused. An area of Permian rocks, of considerable thickness and extent, overlies the Carboniferous strata of the western slope, while on the eastern side Carboniferous, or still older, strata are overlain by Tertiary or Post-Tertiary rocks extending over the immense steppes of Siberia. Cretaceous strata occur in the southern portion of the chain, while a large number of quartz veins, some of which contain gold, are met with in the south-eastern slope.

The gold of the Ural Mountains occurs under two distinct conditions, namely, in original deposits, and in detrital beds of auriferous sands. In original deposits the gold may either be enclosed in quartzose veins, or be disseminated in various rocks. Beds of auriferous sands may be deposited either near the original sources of the gold, or have been transported by the action of water and accumulated at a considerable distance from them.

Deposits of gold enclosed in solid rock are worked in the district of Beresovsk in the southern Ural, and in the districts of Werkh-Issetsk, Newiansk, and Goroblagodatsk. Other deposits which, like the above, principally occur in Asia, have also been worked.

The Beresovsk veins are especially interesting on account of the influence exercised upon them by the country rock. In this locality the crystalline schists are traversed by dykes of finely granular granite, and it is only in the vicinity of these that the quartz veins are found productive. The granite near the auriferous veins is impregnated with iron pyrites which has become partially converted into brown iron ore; this variety of granite has received the name of "beresite." The average yield of the quartz veins which have been worked is thirteen grammes, or about eight pennyweights, to the tonne. The gold is accompanied by iron pyrites, galena, grey copper, plumosite, brown hæmatite, crocoisite, pyromorphite, vauquelinite, bismuth ochre, and native silver. A large number of gold deposits belonging to this class doubtless exist in the Ural, but a relatively small number only have been worked.

In auriferous sands the gold occurs in fine particles which can rarely be detected by the naked eye. These sands are accumulated in beds varying from the thinnest layer to above twelve feet; their ordinary thickness is, however, between eighteen inches and three feet. Their extent is as variable as their thickness, but their length rarely exceeds 1,500 feet. The auriferous bed of Balbouk is, however, about two miles in length, while the longitudinal extent of another deposit exceeds three and a half miles. The width of such accumulations is sometimes very small but, generally speaking, varies between 60 and 300 feet. The auriferous detritus of the Ural is usually found either in valleys or the beds of streams or rivers, and, besides yielding gold in the form of dust or fine grains, sometimes furnishes nuggets of considerable size, the largest of which, weighing 1,158 troy ounces, was found in the district of Miask. The rocks underlying these deposits are of various kinds, including granite, gneiss, beresite, augite-porphyry, serpentine, chlorite schist, talc schist, clay slate, limestone, &c., and wherever a depression occurs in the surface of the bed-rock the proportion of gold increases. These beds, which are mainly composed of gravel, sand, and clay, associated with water-worn fragments of various rocks, contain, in addition to native gold, platinum, iridium, palladium, iridosmine, titaniferous iron ore, iron pyrites, garnet, zircon, diamond, and many other minerals. Wherever magnetic iron occurs to any large extent the percentage of gold in the sand almost invariably becomes greater. The age of these alluvial beds is comparatively recent, since remains of *Elephas primigenius* and *Rhinoceros tichorhinus* have at various times been found in them.

Vein mining is still carried on in the Urals, although upon a somewhat limited scale, the district of Beresovsk, in which veins of gold-bearing quartz have long been worked, being still the principal centre for this class of mining. Since 1886 the production of reef gold in the Urals has increased, but has correspondingly diminished in Siberia.

It appears, from official returns relating to the placers of the Ural Mountains, that 5,300 kilogr. of gold, equivalent to 170,400 oz. troy, were obtained in 1875 from 4,240,000 tonnes of auriferous sand, which corresponds to about twenty grains of gold per tonne of material washed.

Almost the whole of the gold produced in the Russian Empire is obtained by placer mining. In 1890, reef gold formed only 7 per cent. of the total output of Russia, and of this amount 86 per cent. came from the Urals and only 14 per cent. from Siberia. The total yield from the year 1753, when gold washing was first commenced, to the end of 1876, amounted to 31,427,681 oz., of the approximate value of £128,000,000.

The annual production of gold in Russia from the beginning of 1867 to the end of 1877 is given in the following table:—

Year.	Number of Workings	Quantity of Sand and Material washed.		Quantity of Gold extracted.		Approximate Value of Product.
		Poods.	Tons.	Poods.	Oz.	£
1867	878	968,423,325	15,607,179	1,650	868,656	3,648,355
1868	993	1,177,288,244	18,973,261	1,711	900,768	3,783,225
1869	1,129	1,054,570,392	16,995,531	2,007	1,056,591	4,437,682
1870	1,208	983,475,095	15,849,754	2,157	1,135,560	4,769,352
1871	978	1,081,518,424	17,429,828	2,400	1,263,500	5,306,700
1872	1,055	1,044,027,585	16,825,623	2,331	1,227,172	5,154,122
1873	1,018	954,648,764	15,385,187	2,025	1,066,070	4,477,494
1874	1,035	937,578,045	15,110,074	2,027	1,067,120	4,481,904
1875	1,092	1,007,293,492	16,233,613	1,996	1,050,802	4,413,368
1876	1,130	1,022,543,362	16,479,381	2,054	1,081,339	4,541,623
1877	—	—	—	2,430	1,279,293	5,373,030

The following table[1] shows the production of rough gold in Russia during more recent years:—

	Ounces.
1879	1,386,000
1880	1,391,500
1881	1,181,850
1882	1,162,500
1883	1,149,400
1884	1,147,300

[1] *Zeitsch. f. Prakt. Geol.* 1894. F. Pošepny, "Golddistricte von Berezov und Mias," *Archiv. f. Prakt. Geol.* ii. 1895, p. 510. *The Mineral Industry*, iii. 1894, p. 590.

	Ounces.
1885	1,061,500
1886	1,075,450
1887	1,120,800
1888	1,130,650
1889	1,197,900
1890	1,265,400
1891	1,254,550
1892	1,369,900
1893	1,382,600

This rough gold is sent to a Government melting office; on the average it produces about 95 per cent. of bar gold, 900 per mil. fine.

Of the above amounts Siberia furnished the largest proportion, the remainder coming from the districts of Perm and Orenburg in European Russia, supplemented by small contributions from Finland and the district of the Kirghese. Important concessions on the part of the Government have, of recent years, conferred additional advantage upon private mine owners, and, under these new conditions, out of the 2,430 poods of gold produced in 1877 no less than 2,275 came from private undertakings, and only 15 poods from the mines of the Crown and State.

During the last ten years the production has been distributed as follows:—

	Per cent.
Eastern Siberia	67·6
Urals	25·7
Western Siberia	6·6
Finland, &c.	0·1
	100·0

The chief districts[1] in Eastern Siberia are the Amur district, which produced about 240,000 oz. in 1890, and seems to be still increasing its output; Yeniseisk, which has fallen off somewhat of late, producing about 100,000 oz.; and Transbaikal and Yakutsk, especially in the valley of the Lena, where some of the richest placers exist; in the above year this river produced at the rate of about 260,000 oz. In Western Siberia the Governments of Semipalatinsk and Akmolinsk, and in the Urals the

[1] *The Mineral Industry*, 1894, *loc. cit.*

districts of Mias and Berezov are the chief producers. Gold placers were worked in the Caucasus in 1875, but were abandoned; a vein of gold quartz is, however, said to have been discovered and opened up in Nagoltchik in 1895.

According to Pošepny (*loc. cit.*) the average richness of the Berezov mines is about 12 grammes of gold to the tonne (about 8 dwt. to the ton); the prevailing direction of the veins is north and south and they are connected with the existence of masses of eruptive beresite or quartz porphyry; and it is only exceptionally that they continue into the slates through which these eruptive rocks have penetrated. He looks upon the fissures as having been formed by the contraction of the eruptive masses, and holds that the gold was brought in by solutions that penetrated wherever they found space, and which have also mineralised to a small extent many of the rocks in the immediate neighbourhood of the mines, such as granite, beresite, serpentine, and diorite, all of which carry small amounts of gold. In the Mias district the gold veins occur chiefly in greenstone dykes and in the metamorphic rocks in their immediate neighbourhood, whilst serpentine often occurs in company with the greenstone. The average richness of the Ural gold quartz is said[1] to be about 2·75 oz. to the ton, whilst the placer sands have averaged 0·4 oz. to the ton. In Western Siberia the sands average 0.27 oz. to the ton, whilst the richness of the sands in the various districts of Eastern Siberia is as follows:—

	Ounces per ton.
Yenisseisk	0·24
Yakutsk	0·82
Transbaikal	0·40
Amur	1·30
Coast	0·40

The total gold output for 1894 is given as 1,337,600 oz.

Platinum usually accompanies gold in the auriferous sands of the Ural, and is not often met with otherwise than in association with that metal; it has, however, in some few cases, been found without any accompanying gold, as in the placers of Taguilsk, Goroblagodatsk, and Bisersk. It has rarely been found in any considerable quantities in its matrix *in situ*, although small grains of platinum are said to have been occasionally observed in the

[1] *The Mineral Industry*, iii. 1894, p. 591.

auriferous quartz of the Beresovsk mines. It has recently been found in serpentine at Goroblagodatsk (*see* p. 186). The entire production of this metal is obtained from placer washings belonging to private individuals, situated in the northern portion of the Government of Perm. At Taguilsk and Bisersk, where the deposits yield platinum usually unaccompanied by gold, the bed and edges of the platiniferous area are described as being formed of serpentine and peridotite, fragments of which predominate among the rocks occurring in the sand. Among the materials forming the deposit are also fragments of talcose and chloritic schists, together with chrome iron ore, and a conglomerate composed of serpentine, peridotite and chromite, united by a calcareous cement.

From the occasional occurrence of grains of platinum in fragments of serpentine and peridotite, the alteration of which last-named rock is believed sometimes to result in the formation of serpentine, it is generally supposed that that metal originally existed in the form of particles disseminated through rocks belonging to this class. This view relative to the original source of platinum would appear to be corroborated by the fact that, in the district of Miask and in other localities where platinum is found in auriferous sands, those portions of the doposit which rest on serpentinous rocks are always most productive of this metal. It has also been observed that the auriferous sands of the river Mias contain platinum so long as its waters flow over serpentinous rocks, but that, below them, the platinum gradually diminishes in quantity and finally disappears. Platinum is usually accompanied by gold, chrome iron ore, iridium, and iridosmine; and, although generally occurring in small fragments, is sometimes found in the form of nuggets of considerable size, the largest of these yet found weighing about 22 lbs. The average yield of platiniferous sands varies from 4½ to 6 dwt. of platinum per tonne, but, in exceptional cases, it has been known to afford as much as 1½ oz. per tonne. Platinum was first discovered in the Nijne-Taguilsk district in 1825, and from that date to 1892 the production amounted to 3,640,000 oz.[1] (113,211 kilogr.).

The production of platinum in Russia during the ten years ending December 1876, amounted to 590,296 oz. troy, equal to an average annual yield of 59,030 oz. The average quantity of this metal annually produced in the Ural district, about 1880, is estimated at about 53,000 oz.

[1] *The Mineral Industry*, 1894, p. 596.

The following table[1] shows its rate of production:—

	kilogr.	
1862	2,325	crude platinum
1872	1,381	"
1882	4,084	"
1888	2,717	"
1889	2,636	"
1890	2,833	"
1891	4,242	"
1892	4,410	"

The amount produced in the last-named year was obtained by the treatment of about 1,350,000 tonnes of sand, containing on an average 3·3 grams of platinum per tonne.

No silver or lead mines appear to be at present worked in the Urals, the principal supply of these metals coming from Siberia. A quartz lode at Ekaterinenburg, running south-east and north-west, and traversing a dyke of beresite enclosed in talc schists and clay slates, is known to be argentiferous. This vein contains, near the surface, brown hæmatite, azurite, cerussite, pyromorphite, crocoisite, native silver, and stephanite; while at greater depths iron pyrites, galena, and grey copper ore make their appearance. More or less galena also frequently occurs in the veins of auriferous quartz; but true deposits of lead ore occur in the Alapaewsk district, where cerussite, associated with brown hæmatite, forms nests in a brownish clay. In the Slatoust district galena is found in quartz veins traversing Silurian limestone. No returns of silver or lead from the Ural Mountains are included in the official statistics for 1876.

The occurrence of occasional pebbles of cinnabar among the auriferous sands of the Urals, renders it not improbable that deposits of that mineral may, at some future period, be discovered.

Among numerous other copper deposits, some of which have been but imperfectly examined, is the celebrated cupriferous mass of Miednoroudiansk, in the district of Nijne-Taguilsk, where a metamorphic schist containing the ore is enclosed in limestones belonging to the Upper Silurian formation. The beds course N. 20° E. and dip 7° S.E., but their continuity and regularity are much interfered with by the occurrence of numerous faults.

[1] De Launay, *Statistique de la Production des Gîtes Métallifèrès*, p 186. C. Le Neve Foster, *First Annual General Report upon the Mineral Industry of the United Kingdom*, 1895, p. 87.

In the lower horizons these rocks are comparatively little altered, and contain, principally, iron and copper pyrites; while, in the upper, the rock contains oxidised minerals, and is transformed into a clayey ferruginous mass. In this part of the deposit, which is a true gossan, are found cuprite, malachite, azurite, magnetic iron ore, native copper, libethenite, brochantite, &c. This ore sometimes contains 23 per cent. of copper. In 1836 a block of malachite was found in this locality weighing 330 tonnes. From 1814 to 1877 this deposit, which may probably have some relation to the diorites of the Wisokaïa Mountain, produced 2,590,000 tonnes of copper ore. Copper ore deposits are numerous in the Ural Mountains, although very few of them have been worked with the exception of the Miednoroudiansk Mine, which annually produces about 1,200 tonnes of ore. All the other copper mines in the Urals appear to have been abandoned. The bedded deposits of the western slope cannot be considered as having any geological connection with this range of mountains, but as they belong, administratively, to the same group they may be here mentioned.

These deposits occur in the Governments of Perm, Wiatka, Kazan, Ufa, Samara and Orenburg, and belong to two different formations, the Permian and the Triassic; it is, however, generally impossible to say precisely to which of these two formations each particular deposit belongs. The copper occurs in the form of blue and green carbonate, black oxide, cuprite, copper ochre, volborthite, and, very rarely, as native copper. The sulphuretted minerals, copper sulphides, iron and copper pyrites, and gray copper ore, constitute but a small proportion of the ores present. In 1875 these bedded deposits of copper ore produced 20,000 tonnes of ore, from which 800 tonnes of copper were obtained.

Nickel occurs at Rewdinsk in an almost vertical quartz lode, about six feet in thickness, traversing chloritic slate and serpentine in a direction N. 30° E. The ore is stated to be a hydrated silicate represented by the formula $3R\ SIO_3 + 2H_2O$, in which R represents principally nickel; it contains 18 per cent. of nickel and 12 per cent. of iron, and has received the name of rewdinskite. Cobalt and zinc ores are almost unknown; but several deposits of manganese and chrome ores are worked in the Ural. Of the latter some three or four thousand tonnes are raised annually.

Magnetite occurs in a number of large deposits on the eastern side of the Ural chain, but of these only a small number are worked. The magnetite deposits of the Blagodat Mountain and of the Wisokaïa Mountain are well known, and have been described in various Russian and French works.

The Blagodat Mountain[1] consists of augite-porphyry passing into uralite-porphyry, the summit being capped by a compact basaltic rock. The magnetite is distributed in strings and irregular masses, and is very compact, but contains iron pyrites, calc spar, apatite, mica and analcime.

The magnetite which affords the best iron in Russia is obtained from the Oula-Outasse-Taou Mountain, but only a small quantity is raised. In addition to the above-mentioned deposits of magnetite, many others of less magnitude occur in the Urals. These usually form irregular masses, lodes, or bedded lodes, in hornblendic and pyroxenic rocks, as well as in syenites and in crystalline schists. Red hæmatite is found in many places, but it occurs principally in small masses subordinate to brown hæmatite, and rarely as an independent deposit.

Brown hæmatite is the principal and most abundant iron ore of the Urals, and is extensively worked in various localities. Brown hæmatite deposits occur under very varying conditions, namely :—

1. In small irregular masses in plutonic rocks.
2. As beds in metamorphic rocks.
3. In beds at the contact of the metamorphic rocks with Silurian limestones,
4. In deposits at the contact of metamorphic and plutonic rocks.
5. In accumulations in the lower horizons of the Silurian formation.
6. In beds in clayey sandstone of Carboniferous or Devonian age.
7. As accumulations in the form of nests in Silurian or Carboniferous limestones.
8. As accumulations in alluvium.

Spathic iron ore is by no means plentiful, but sometimes accompanies brown hæmatite, as in the Irkouskane Mountain, which annually yields about 1,650 tonnes of this ore. Sphærosiderite also occurs in the Ural, being worked in carboniferous sandstone with an annual production of 15,500 tonnes.

The Timan chain, situated in the extreme north, is very thinly inhabited, and comparatively little is known of the mode of occurrence of its minerals.

[1] H. Müller, *Berg. und Hüttenm. Zeit.*, 1866, p. 54.

The Caucasus.—The oldest rocks of this chain are believed to be of Jurassic age, and the most important metalliferous deposits are those of manganese and copper ore. Among the copper deposits the lodes of Alwerd, Sitsimadane, Kawart, and Artan, with the irregular mass of Kiadabek, may be cited as the most important.

The usual gangue is quartz, sometimes associated with gypsum and, more rarely, with heavy spar, in which latter case the lode is seldom rich. The ore generally consists of iron and copper pyrites, with various products of their oxidation. Blende sometimes occurs in more or less considerable quantities, as at Kiadabek, where a nest of argentiferous galena has been discovered. In other cases the ore consists of a mixture, in varying proportions, of argentiferous galena and copper ores, as in the Dambloud deposit.

Deposits of lead ore, properly so-called, exist only in Ossetie to the north of the chain, where they form lodes of which both the gangue and country rock are quartz, protogine, heavy spar and limestone. The ore consists of galena, blende, iron and copper pyrites, with products of their oxidation.

A deposit of cobalt ore has been found at Dachkessan, Government of Elisabethpol, which takes the form of a dyke of diorite impregnated by cobalt ore associated with iron and copper pyrites. The cobalt ore is almost entirely free from nickel; the workings were for a time abandoned, but in 1892 the production was 19 tonnes of ore.

Among the deposits of iron ore that of Dachkessan is one of the most important, and consists of a thick bedded lode of magnetite; while at Tchatach there is a large irregular mass of diorite impregnated with iron glance.

Manganese is found in the valley of the Kwirile River, forming a bed of pyrolusite in Miocene sandstone.

Very important deposits of manganese ore have been opened up in the Caucasus since 1879, the chief districts being Tiflis, Kutais, and Saropansk. The ores, which occur in very flat-lying beds, are known over an area of nearly sixty square miles. There are from six to eleven beds of different qualities separated by thin partings, forming a total of from 6 to 16 feet in thickness, the individual layers being often very thin. The deposit is intercalated between two beds of limestone of Eocene age, and is associated with thin layers of sand, the ore occurring either as an oolitic stratum or as lumps disseminated in a bed of clay, the minerals being chiefly pyrolusite and manganite. The production[1] of this ore has been as follows:—

	Tons.
1879	871
1881	11,000
1886	73,000
1888	32,000
1890	169,000

The importance which this district has assumed compared to the other Russian manganese producing centres may be seen from the following table:—

District	1878. Tons.	1890. Tons.
Caucasus	—	168,900
Urals	190	2,300
Southern Russia	—	8,500
Totals	190	179,700

Southern Russia.—The Government of Ekaterinoslav has recently come into prominence as an iron producing centre, owing to the opening up of the coal basin of the Donetz[2]; in this same region there are also numerous small deposits of brown hæmatite of a moderate degree of purity. The source of most of the iron ore is the extensive series of deposits occurring about Krivoi-Rog in the Government of Cherson. These consist of highly inclined beds of ferruginous quartzite carrying about 40 to 45 per cent. of metallic iron; between these strata occur large lenticular deposits of magnetite and specular ore, whose longer axis is parallel with the strike of the beds; their length is from 650 to 2,000 feet, their thickness 65 to 350 feet, and their contents range from 300,000 to 3,000,000 tons, the ore assaying 60 to 65 per cent. of metallic iron. These deposits have been traced for a length of some 35 miles. In 1894 there were twelve mines in existence, producing annually some 800,000 tons of ore.

Manganese ore also occurs near Nikopol in the Government of Ekaterinoslav in the form of strings of ore disseminated in a bed of clay. These deposits have only been opened up recently.

Quicksilver was discovered in the Donetz coal basin at Nikitofka in 1879, and has been actively worked since 1886.

[1] *Journ. Iron and Steel Inst.*, 1895, i. p. 290.

[2] G. Kamensky, "The Ironworks of the South of Russia," *Journ. Iron and Steel Inst.*, 1895, ii. p. 70.

The ore there found is cinnabar, which exists as an impregnation in a bed of sandstone of Carboniferous age, inclined at an angle of 50°; the roof is formed by shales and the floor by a stratum of very compact sandstone, whilst there are numerous small fissures carrying cinnabar. The mode of occurrence is in many respects comparable with that of Almaden. The ore is said to contain from 0·4 to 1·1 per cent. of mercury.

The amount of metal produced recently[1] was as follows:—

	Tonnes.
1887	64
1888	165
1889	167
1890	292
1891	324
1892	343

POLAND.—It is probable that mines were worked in Poland during the twelfth century, and from the commencement of the fifteenth century to the end of the sixteenth more lead was produced in Poland than in any other country in Europe. The calamine deposits were discovered at the commencement of the present century, and a more liberal mining law, which was promulgated in 1870, has exercised a considerable influence on the development of the industries of the country.

The deposits of galena in the dolomites of the Muschelkalk are of great historical interest, as they have been worked for many centuries. The most remarkable lead mines are those near Olkusz and Boleslaw. The production of lead from the latter mines was very large during the sixteenth and seventeenth centuries, but fell off considerably towards the end of the eighteenth. At the commencement of the present century calamine deposits were discovered, and the galena is now worked subordinately to the zinc ores. In 1876 only 3,895 tonnes of lead ore were obtained, and since that time the output has dwindled down to practically nothing.

Deposits of lead and copper have been long known near Checiny and Kielcé. The lead ores occur in lodes in Devonian quartzites, and have been worked from the fifteenth century. The copper ores, which consist principally of malachite and azurite, have been worked near Kielcé, at Miedziana-Gora, and at

[1] *Zeitsch. f. Prakt. Geol.* 1894, p. 427. C. Le N. Foster, *Mineral Industry of the United Kingdom*, 1895, p. 87.

Karczovska. The working of these deposits dates from the fifteenth century. During the ten years terminating in 1826, 3,360 tonnes of copper ore were obtained; but the production has since entirely ceased.

The ores of zinc found in Poland are carbonate of zinc, silicate of zinc, zinciferous dolomite stained red by oxide of iron, and zinciferous limestone. The majority of these are found in the dolomite of the Muschelkalk formation. These ores always occur as irregular deposits, or nests, varying in thickness from a few inches to twelve feet, as is also the case in the Scharley Mine in Silesia. The same deposits extend into Poland and are worked at the Barbe Mine. Near Boleslaw the deposit forms a mass, 2,000 feet in diameter and 50 feet in thickness; but the percentage of zinc in the ores is very variable in the different mines. In 1876 six mines produced 59,878 tonnes of zinc ore, and during the same year three zinc works yielded 4,506 tonnes of zinc; in 1893 the production was 60,200 tonnes of ore, and 4,600 tonnes of zinc.

Numerous deposits of iron ore occur in the south of Poland, and iron ore mines are worked near the small town of Daleszycé, where deposits of brown hæmatite containing 40 per cent. of iron are enclosed in rocks of Devonian age. The Carboniferous formation of Poland contains numerous beds of sphærosiderite, of which the thickness is very variable; but this mineral is often found in large masses and is very extensively worked. Brown hæmatite, containing from 25 to 33 per cent. of iron, also occurs in the Muschelkalk, and is worked at Bendzin, Czeladz, Sievierz, and Slawkow. The iron ores which occur in the Keuper, are, however, much more important, and consist of brown hæmatite and sphærosiderite. The brown hæmatite contains from 35 to 45 per cent. of iron, and the sphærosiderite only from 27 to 35 per cent.; but the latter constitutes the larger portion of the iron ore raised in Poland.

In 1876 iron ore was raised from 79 mines in Poland, the total production of the country being 107,600 tonnes; this yielded 31,168 tonnes of cast iron.

The Altai.—The number of ore deposits which have been discovered in the Altai is very large, amounting in the aggregate to several thousands. The larger number of them occur in the western extension of the chain, in the neighbourhoods of Schlangenberg, Riddersk, Nikolajewsk, and Siranowsk. Several mines are, however, worked near the town of Salair, north of the main chain, while on the other hand the eastern portion is but little known, and no ore deposits are believed to be worked in this region. All the different veins exhibit similar characteristics, being almost without exception lodes traversing sedimentary rocks belonging to the Silurian, Devonian, and Carboniferous periods. Lodes do not often occur in the crystalline slates, and still more rarely in granite. Granites, porphyries and greenstones constantly occur in the vicinity of the lodes, and several mines are worked in porphyry. The filling of the lodes chiefly consists of heavy spar, quartz, and various sulphuretted ores; the latter are, however, usually much altered near the outcrop, and crystallised minerals are rare.[1]

The principal silver mines of Russia are in the Government of Tomsk in the Altai, where veins of argentiferous ores occur. The Altai is returned as having produced in 1891 lead to the amount of 685 tonnes, and 9,750 kilogr. of silver.

At the Tschudack Mine, in the Altai, a copper lode from eighteen to twenty-four feet in width is worked in quartz-porphyry; the veinstone is quartz, enclosing copper ores in strings and leaders. In the centre of this lode there is said to be a leader of ore six feet in width containing but little quartz. At a certain depth the ores consist of copper and iron pyrites and copper glance; near the surface various products of oxidation prevail.[2]

Auriferous sands, frequently containing platinum, are extensively worked in the Altai. In the mining district of Nertschinsk, in eastern Siberia, in the proximity of syenite and granite, crystalline limestones alternate with sandstones, and are traversed by irregular veins which, occasionally, widen out to irregular masses, especially near the contact of dissimilar rocks. These deposits are filled with quartz, calc spar, and brown ironstone, in which galena fahlerz, molybdenite, iron pyrites, copper pyrites, and blende are enclosed, and are at times worked for silver.[3]

In Russian Turkestan, deposits are known of gold, silver, lead, copper, iron, manganese, and arsenic; but in spite of their large number a few only are worked. Gold placers are wrought upon a small scale, but the deposits of other metals for the most part remain unworked.

The production of tin in Russia—entirely from Finland—in 1879 amounted to only two tons. Zinc gave an annual average of

[1] B. v. Cotta, *Der Altai*, Leipzig, 1871, p. 246.
[2] *Ibid.*, *Berg. und Hüttenm. Zeit.* 1870, p. 29.
[3] Pischke, *Neues Jahrb. f. Min.* 1876, p. 898.

4,337 tons, five years previous to 1879, but in that year fell to 4,236 tons. Copper decreased from 3,496 tons, the yearly average of the same quinquennial period, to 3,064 in 1879. Lead increased from 1,010 tons, average, to 1,331 tons in 1879. No nickel was extracted in 1879. In the same year 15 tons only of cobalt ores were raised. In 1892 the figures were not very different being: Zinc, 4,374 tonnes; copper, 5,010 tonnes; lead, 930 tonnes.

The precious metals showed a marked increase during the period 1874 to 1878. In western Siberia the production of gold increased slightly, and in the Urals considerably. At the end of 1879 the number of gold mines belonging to private individuals was in eastern Siberia 1,522, in western Siberia 291, and in the Ural 1,233, making a total of 3,046.

FINLAND.—The copper and tin ore deposits of Pitkäranta [1] are worked on the north shore of Lake Ladoga, where the rocks consist, principally, of red coarsely granular granite and crystalline slates, Veins of granite frequently occur in which red orthoclase sometimes predominates to such an extent as to be worked for the manufacture of porcelain. Metalliferous deposits are also numerous, the ore occurring as impregnations of copper and iron pyrites, galena, and magnetic pyrites, the gangue being usually quartzose. The only deposit which has been advantageously worked is a bed of sahlite impregnated with copper pyrites and tinstone. Upon this, which occurs in the granite, mining has been carried on for above fifty years. This bed, which for a length of nearly one mile and a half has been opened upon by six shafts, has a very constant thickness of about fifteen feet, strikes from east to west, and dips from 40° to 50° S.

The most easterly point worked is opened by No. 1 Clée Mine, where the entire mass of the deposit is divided by parallel fissures into five beds sharply divided from one another; the ore varies much in richness, and the country rock does not contain any tinstone. Fig. 102 represents a transverse section across the deposit, in which the band marked *a* is the richest, and contains copper ores only; *b* and *c* contain no ore, *d* contains copper and iron pyrites, while *e* is unproductive.

A little more than half a mile west of this point the rock acquires in the No. 4 Omilianoff Mine a much darker colour, and encloses a bed of dark granular granite three feet in thickness. Here the ore occurs differently, for, whereas in the No. 1 Clée

[1] G. v. Schoultz-Ascheraden, *Berg. und Hüttenm. Zeit.* 1876, p. 280.

Mine the copper pyrites is finely divided, here it occurs in compact masses up to the size of the fist, and is often associated with other minerals, such as malacolite, hornblende, quartz, calc spar, garnet, mica, felspar, fluor spar, talc, iron pyrites, magnetite, blende and tin ore. Iron pyrites occurs in crystals,

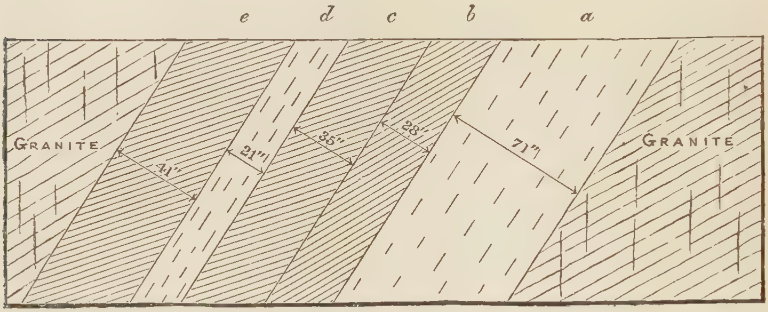


FIG. 102.—Clée Mine, Pitkäranta; section.

which sometimes attain a weight of 5 lbs. Neither galena nor magnetic pyrites appear to be present.

Fig. 103 represents a transverse section of Mine No. 3, which is worked for tin ore only. In this section *a* is sahlite with a little copper pyrites, *b* granite without ore, *c* sahlite with tin ore, *d* sahlite with a little tin ore, *e* granite with tin ore; *c* and *e* are the

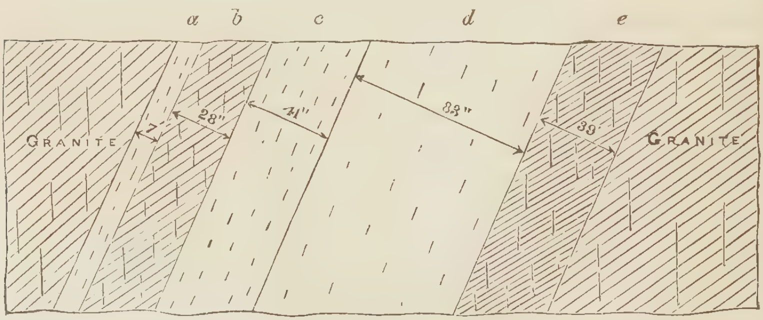


FIG. 103.—Omilianoff Mine, Pitkäranta; section.

richest in tin, and in *d* tin ore can just be detected, but is entirely absent in the others.

In 1880 Pitkäranta produced 25,513 centners or 1,085 tonnes of copper ore, and 482 centners[1] or 20·5 tonnes of tin ore.

[1] 1 centner = 42·53 kilogrammes.

The production of Finland in 1880 was as follows[1] :—

Iron ore . .	4,120	centners or	175·2	tonnes
Copper ore .	31,756	„ „	1,350·5	„
Tin ore . .	482	„ „	20·5	„
Zinc ore . .	5,276	„ „	224·4	„
Lake ores .	880,090	„ „	37,430·2	„

From 240,663 cubic feet of auriferous sand 17,609 grammes of gold (566 oz.) were obtained.

E. H. Furuhjelm, director of the Office of Mines, Finland, in a letter to the editor of *Iron*[2] says that the total amount of the gold washed from auriferous sands in North Finland, in the year 1881, was 20,600 grammes, which, at 3·20 francs per gramme, gives a total value of 65,920 francs, or £2,637.

During the ten years from 1881 to 1890 the production of gold in Finland was as follows :—[3]

1881	658	ounces
1882	606	„
1883	342	„
1884	—	„
1885	171	„
1886	131	„
1887	171	„
1888	394	„
1889	867	„
1890	525	„

General Summaries of the Approximate Production of Metals and Metalliferous Minerals in the Russian Empire during the Years 1880 and 1892.

1880[4]

	Poods.	Tons.
Iron ore raised	62,493,424	1,003,147·0
Gold produced	2,642	42·4
Platinum	180	2·9
Silver	616	9·9
Lead	69,947	1,112·0
Copper	195,518	3,138·0
Zinc	267,800	4,298·0
Sulphur	5,500	87·0
Chrome iron ore . . .	503,503	8,081·0

[1] *Berg. und Hüttenm. Zeit.* 1882, p. 247.

[2] February 10th, 1882, p. 106.

[3] F. Pošepny, *loc. cit.*

[4] *Engineering*, xxxv. 1883, p. 29.

1892[1]

	Quantities.	Values.[2] £
Gold	43,030 kilogr.	5,230,400
Silver	11,200 ,,	57,000
Platinum	4,410 ,,	139,600
Antimony ore . . .	1,240 tonnes	2,000
Chrome iron ore . .	3,000 ,,	1,877
Cobalt ore	20 ,,	—
Iron pyrites	14,120 ,,	11,300
Manganese ore . . .	203,460 ,,	92,700
Pig iron	1,072,651 ,,	4,589,399
Lead	885 ,,	12,290
Copper	5,377 ,,	369,100
Tin	9½ ,,	880
Zinc	4,372 ,,	104,000

TURKEY.

It is well known that many parts of the Turkish Empire are rich in minerals, but the conditions of the country have not been such as to foster mining enterprise. Of recent years a little more encouragement has been given to miners, and a little work is being done, though the chief mineral products, meerschaum and emery, are non-metallic minerals. The following data are taken from a paper on the subject by Dr. W. May.[3] There are several copper mines worked by the State; the best known of these are the mines at Arghana, near Diarbekir, on the river Tigris. This mine produces about 120 tonnes annually of black copper containing 75 per cent. of metal; the mines at Batman produce about 720 tonnes, and those at Okka about 923 tonnes of black copper of the same quality. Another mine near Diarbekir produced 790 tonnes of copper ores in 1894.

Lead and silver, with a little gold, are also mined by the State at Bulgardegh, where about 1,500 kilogr. of silver are produced annually. The most important silver-lead mines are at Hodsha-Gernish (Balia) belonging to the "Société des Mines de Balia-Kara-aïdin," which produce about 4,000 tonnes of ore annually. An English company, the "Asia Minor Mining Company," is working silver ores at Lidshesi, and producing about 3,000 tons of ore per year. Important mines are being opened on the Kes-

[1] C. Le N. Foster, *First Annual General Report upon the Mineral Industry of Great Britain*, 1895, p. 87.

[2] Exchange is taken at 10 silver roubles = £1.

[3] Dr. W. May, "Die Bergbaulichen Verhältnisse in der Turkei," *Oëster. Zeitsch. f. Berg. u. Hüttenwesen*, May, 1896, p. 223.

senderé peninsula, which district is also rich in manganese deposits.

Numerous important antimony deposits are known and are worked to some extent.

Chrome iron ore of high quality, carrying from 46 to 56 per cent. occurs in great quantities in Turkey; the present output is 20,000 tonnes per annum, and this could readily be greatly increased should the demand warrant it. In the province of Angora, in Anatolia, several mineral deposits are being opened up by an English company.

ASIA AND OCEANIA.

THE INDIAN EMPIRE.

ALTHOUGH the useful metals or their ores are, in British India, scattered over vast areas, they are, with but few exceptions, so sparingly disseminated as to be but seldom capable of being worked with advantage. Gold occurs in the sands of a large number of its streams and rivers, but usually in such minute quantities as to afford a pittance of only a few pence daily to a limited number of indigent washers. In addition to gold thus obtained from the sands and gravels of rivers, abundant evidence exists of that metal having been anciently mined from auriferous veins by means of shafts, galleries, and other excavations. There would appear, however, to be no record of the periods at which these works were executed, and we are consequently without any information as to the conditions under which they were conducted, or with regard to the relative values of gold and labour at the time they were in operation. In the majority of cases, therefore, the existence of ancient workings affords but little evidence of the value, according to modern standards, of metalliferous deposits, since they may have been made by forced labour, and at a time when the metals were relatively much more valuable than they are at present. There are occasional exceptions to this general rule, as, for instance, at Mysore, where modern workings have been carried on beneath the level of the ancient ones with highly favourable results. The lead ores of India, always containing a certain proportion of silver, occur disseminated in beds, in intercalated or in irregular deposits, but they are seldom found in true veins. Many of these deposits were formerly worked on a very small scale by the natives, but none of those which are at present known would seem to offer sufficient inducement for the introduction of capital, or for the application of improved modern processes.

Ores of copper are of even more frequent occurrence than those of lead, but like those of that metal are seldom found in regular lodes, but occur, on the contrary, in beds and bedded veins, as well as in the joints of various rocks. These ores were formerly worked by native smelters, who obtained from them copper of good quality but at a cost far exceeding that at which it can now be imported.

Iron ores are abundant, and malleable iron has, from time immemorial, been produced from them in charcoal forges blown with a hand blast. In this way both iron and natural steel are still, to some extent, manufactured by the hill men at various points in the interior; but the metal so produced can no longer compete in price with that manufactured upon a larger scale in Europe, and subsequently imported into the country. Numerous attempts have been made to introduce modern processes of iron and steel making into British India, but the results have been unsatisfactory. This repeated want of success is probably in part attributable to various circumstances of a kind often unfavourably affecting enterprises of this description, but is perhaps mainly due to the circumstance that the largest and richest deposits of iron ore are situated at considerable distances from a sufficient supply of suitable fuel.

Gold.—The original derivation of the principal portion of the gold of Peninsular India is doubtless from the quartz veins traversing various metamorphic and sub-metamorphic rocks. There is also reason to believe that in some parts of the country gold occurs, independently of quartz veins, in certain chloritic schists and quartzites as well as, possibly, in one or more varieties of gneiss.

According to Professor Ball, late of the Geological Survey of India:—" The presence of gold either as an original deposit, or as a detrital product from the older rocks, has not as yet been proved in any member of the great Vindhyan formation. But in the next succeeding formation several of the groups included in the Gondwana system are believed to contain detrital gold; of these the evidence seems clearest in the case of the Talchir. It is almost certain, however, that the gold obtained in the Godavari and in its tributary near Godalore or Mungapet, is derived from rocks of Kamthi age, and the gold of the Ouli River in Talchir in Orissa is derived from sandstones, but whether from those of the Barakar or Kamthi groups is not certainly known, as both occur in the same river section. It is of course natural that the sedimentary rocks which first filled the previously existing hollows and basins should contain gold as well as the other materials derived from the degradation of the older metamorphic rocks, but gold is also probably present, though its existence has not yet been proved, in some of the still younger groups.

"In so far as Peninsular India is concerned, the only other sources of gold are the recent and sub-recent alluvial deposits which rest on the metamorphic and sub-metamorphic rocks. Passing to the extra-peninsular regions we meet with evidences of the existence of gold in rocks of several different periods. In Ladak certain quartz reefs which traverse rocks of the Carboniferous period are almost certain to be gold-bearing, as particular streams which rise within their limits contain auriferous sands. In Kandahar gold occurs, as also do some ores of other metals in rocks of Cretaceous age. Here the deposit is an original one, and is connected with the intrusion of trap.

"Lastly, all along the foot of the Himalayas from west to east, from Afghanistan to the frontiers of Assam and Burma, the Tertiary rocks which flank the bases of the hills, and which occur also in the Salt range and in Assam, south of the Brahmaputra, are more or less auriferous. But this gold is all detrital, and was no doubt, in the first instance, derived from the crystalline metamorphic rocks of the higher ranges which are otherwise known to contain gold."[1]

Since the above was written, Mr. R. B. Foote[2] has shown that the chief auriferous deposits of India, or at any rate of southern India, occur in a belt of hornblendic, chloritic and argillaceous schists, associated with more or less hæmatitic quartzite and with eruptive trap rocks, which he proposes to group together under the name of the Darwhar series. These rocks form belts, whose general trend is N.N.W.-S.S.E., overlying unconformably the great

[1] V. Ball, *A Manual of the Geology of India*, part iii. "Economic Geology," p. 176, Calcutta, 1881. This carefully prepared volume, to which I am indebted for a large amount of information, should be consulted by every one specially interested in the mineral resources of British India.—J.A.P.

[2] R. B. Foote, "The Darwhar system, the chief auriferous rock series in South India," *Records of the Geol. Survey of India*, xxi. 1888, p. 40; and xxii. 1889, p. 17.

gneissic series; they have been exposed to vast lateral pressure, by which they have been crumpled into great folds, and have subsequently undergone extensive denudation.

The gold-fields of Madras at one time attracted so much attention and have absorbed so large an amount of British capital, that some description of the auriferous deposits of that portion of British India may be desirable.

The excitement caused by reports relative to the riches of the Wynaad also directed attention to various adjoining areas in southern India where crystalline rocks prevail. Among these the Travancore State has been to some extent prospected, but it does not appear in any of the early accounts as a gold-producing region, and the trade of gold washing seems to be unknown there. Mr. King, who reported on this subject to the Travancore Government, states that the so-called quartz reefs are not really veins, but merely the outcrops of beds of quartzite, associated with felspar, which run with the foliations of the gneiss. Although minute traces of gold may sometimes be detected in these rocks by assay, the amount present is far too small to render them of any commercial value as a source of that metal.

The Wynaad forms a terrace of mountain land lying between the low country of Malabar and the lofty plateau of the Nilgiri Mountains, and is separated into three portions, known respectively as North, South, and South-East Wynaad. The south-eastern division of the Wynaad, in which are situated the principal veins of auriferous quartz, is now included in the Nilgiri district; but with reference to the earlier notices of the occurrence of gold, it will be more convenient to follow Mr. Ball, and to treat it as belonging to the Malabar district, in which it was formerly included. In a report of a joint commission from Bengal and Bombay upon the condition of the Malabar province in the years 1792–93, allusion is made to the fact that the Rajah of Nilambar claimed a royalty on all gold found in his territory, and in the latter year some steps were taken by the then Governor of Bombay to ascertain the value and extent of the gold mines of this region. The next mention of the occurrence of gold in the district is made by Dr. Buchanan[1] in 1807; he alludes to the gold mines of Malabar and states that a Nair who had the exclusive right of mining paid a small annual tribute for the privilege. In the year 1827 Mr. S. Young stated that fine specimens of gold had been

[1] *A Journey from Madras through the countries of Mysore, Canara and Malabar*, London, 1807, i. p. 441.

found to the west of the Nilgiri Mountains in the beds of various streams, and in 1830, Mr. F. H. Barber,[1] who was examined before the Lords Committee on East Indian affairs, asserted that gold was obtained not only in Coimbatore but throughout the tract of country lying west and south of the Nilgiri and Kunda Mountains. He had often witnessed the process of gold washing, and estimated the area over which the soil was impregnated with gold at 2,000 square miles. In the year 1831 Lieutenant Nicolson was appointed to prospect for gold-fields, and also to purchase on behalf of Government. His report as to the extent of the mines and the possibility of their being worked advantageously by British capital, was on the whole sanguine, and he suggested that stamping mills for the treatment of gold quartz should be erected at Coopal. After the receipt of the report of a committee, in 1833, condemning mining in the low country of Malabar as a European industry, the Governor in Council came to the conclusion that it would be inexpedient to work these veins. In 1857 and 1858 attention was again directed to these gold mines by the Collector of Malabar, who described them as extending for a distance of from thirty to forty miles along the western face of the ghâts, and in some places even reaching to their summits. At this time the taxes payable by the rajahs for the right to mine had fallen into arrears, and many of the older miners and their descendants would appear to have migrated to the coffee plantations of the Western Wynaad. Among those who in 1865 were attracted to the Wynaad were two Australian miners, Mr. H. L. Sterne and Mr. G. E. Withers, while shortly afterwards the erection of quartz-crushing machinery on the Skull Reef was due to the enterprise of Mr. J. W. Minchin. The results yielded by this and other appliances erected elsewhere for the same purpose, were not satisfactory, and in 1875 Mr. W. King, Deputy Superintendent of the Geological Survey of India, visited the districts, and his report with a map of the Wynaad was subsequently published.

The gold-bearing area consists of granite, gneiss, and various metamorphic rocks, traversed by veins of quartz, which with their branches are auriferous. He describes the gold as occurring originally in large reefs or veins of quartz, as well as in spurs branching from them, and sometimes in the country rock itself. In certain leaders, as well as in the casings of the veins, gold is

[1] *Journal Med. and Phys. Soc. of Calcutta*, iv. p. 48 ; evidence ordered to be printed, April 2nd, 1830.

sometimes visible either in quartz, in crystals of iron pyrites, or in pseudomorphs composed of limonite resulting from the alteration of that mineral. The gold of the reefs is usually very fine, and occasionally occurs associated with pyrolusite. The prevailing direction of the quartz reefs is from south-south-east to north-north-west, but owing to the irregularity and occasional flatness of their underlie, there is sometimes considerable difficulty in tracing them. Their outcrops are without exception white, and generally speaking it is impossible to say by mere inspection whether they are auriferous or otherwise. The Monarch Reef is said to be traceable for a distance of about nine miles.

Mr. R. Brough Smyth reported on the Wynaad in 1880, and represented the reefs as being generally wider and proportionately richer than those in almost any part of Australia, but there are no deep accumulations of auriferous drift such as characterise the gold regions of that country and of California. Numerous ancient workings indicating very different degrees of mining skill are met with; these comprise open cuttings on the outcrops, vertical and inclined shafts on the reefs, with occasionally levels, and shafts and galleries combined. Some of the vertical shafts, which are perfectly perpendicular, have been sunk in solid quartz to a depth of seventy feet. The rock obtained from these various workings appears to have been ground by hand mullers, washed in a wooden dish, and, perhaps, subsequently amalgamated. The country is so covered by these ancient tailings that Mr. Brough Smyth compares its condition to that of an abandoned Australian washing. The quartz from the veins in this region occasionally contains cavities enclosing minute crystals of native sulphur.

The Wynaad [1] gold region consists of a more or less undulating table-land averaging about 3,000 feet above sea level, and lying at the eastern foot of the Nilgiri Mountains, which, being the highest mountain range of Southern India, rise to a height of some 8,000 feet above the sea. The climate during the greater portion of the year is temperate and equable, but, during the monsoon, the rainfall averages somewhere between 150 and 200 inches. The monsoon of 1882, however, exceeded 400 inches, being the heaviest on record.

The country rock mainly consists of a hornblendic gneiss containing a large preponderance of quartz, and is, as a rule, except in close proximity to the surface, where it is liable to decomposition,

[1] I am indebted to Mr. George Seymour, A.R.S.M., for much valuable information relative to the Wynaad gold-fields.—J.A.P.

extremely hard. No well-authenticated instance of a vein settling down into and "living' in the country rock, has been observed. Owing to this fact, and to the circumstance that most of the quartz has, up to the present time, been sought by shallow adits, but little mining has been carried on which could enable any reliable opinion to be formed respecting the character and continuity of the reefs in depth. No shafts of any importance have been sunk, and some adits which were started to explore the country under favourable topographical conditions had to be abandoned owing to the hardness of the rock, which proved too much for the labour available. The course of the reefs varies from N. 20° to 40° W., the dip being generally easterly, at an angle of from

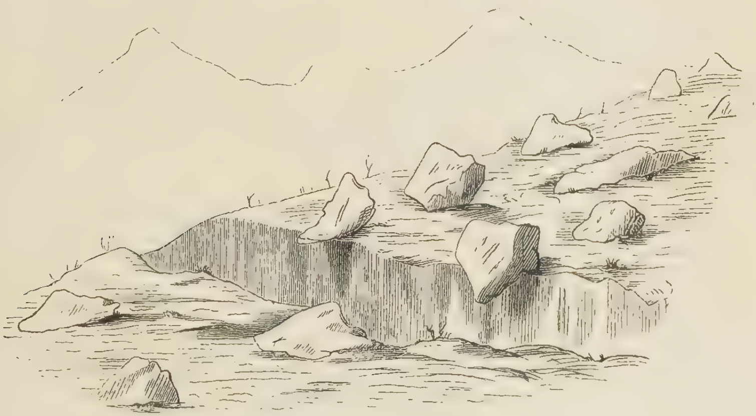


Fig. 104.—Quartz boulders, Wynaad.

30° to 35° with the horizon. Some of the veins appear to incline at a greater angle, but these are exceptions to the general rule.

Perhaps the most noteworthy feature in connection with these deposits is their want of continuity in strike and dip, under circumstances which would lead a casual observer to the conclusion that they were persistent in both. As an instance of this, a presumably stable and continuous outcrop of quartz, on investigation by means of a transverse trench, shown in Fig. 104, proved to be no more than a row of symmetrically disposed superficial boulders, sufficiently angular, notwithstanding, to justify a hasty supposition that they represented the outcrop of a reef. In this case the main axis of the boulders was that of the normal strike of the district, 20° W. of N., yet not a single stone could be found six feet below the surface. In another locality a reef showing a pronounced strike and a width of many yards on one side of a gully, failed to show any trace on the other.

A reef was found parallel to the slope of a hill side, and another lying parallel to it was found by means of an adit. Outcrops having been seen on the slope above underlying in the same direction, it appeared probable that other parallel veins would be found; yet after driving a cross-cut for a considerable distance through the hill none were discovered. In another instance a strong outcrop some nine feet in thickness was discovered on the brow of a hill, but all explorations to prove it in depth were unsuccessful, notwithstanding an exceptionally favourable contour of the ground, and no reasonable doubt can exist that it pinched out within a short distance from the surface.

The tendency of reefs to dip with the hill sides is common in the Wynaad, but it is, however, possible that the contour of the hill itself may sometimes be due to the projecting influence of a reef, which, acting as a capping or shield, protects it from the destructive effects of the monsoon for an indefinite period. The landslips which occur during and subsequent to the monsoon have, in many cases, had the effect of dislocating the reefs, and in some instances of causing one reef or ledge to be regarded as two distinct and independent veins.

Mr. J. Darlington, who visited these gold-fields in 1883, and who had consequently the advantage of examining the workings of the various mines when in a more advanced stage, is of opinion that true veins of auriferous quartz sometimes occur in the Wynaad. Irregular patches, lenticular interfoliations, and bedded veins are, however, more frequent; and in not a few instances what had been taken for the outcrop of a vein has proved to be nothing more than a quartz boulder fallen from a reef situated at a higher level.

The bedded reefs usually dip with the surface of the hill in which they are enclosed, and are often covered by a clay-like material resulting from the decomposition of the superincumbent gneiss; while the rock below has been to some extent protected from alteration by its capping of quartz. In other cases, the quartz has become fissured, and the rock beneath has been reduced to the state of clay, in which portions of the reef, which have become detached, have been embedded, as shown in Fig. 105, which represents a section of Rhodes Reef after a drawing by Mr. Darlington. At right angles to this section the reef forms a saddle or anticlinal.

A very large number of companies were formed to work in this field, and it is said that four and a half millions sterling have been invested in it. Scarcely any of these companies survived in 1896, the results having been uniformly disastrous, and the results of twenty years' mining being estimated at less than 18,000 oz.[1] The Indian Gold Mines Company, Limited, in 1892 crushed 11,125 tons of quartz, and got ninety ounces of gold! The rocks of the district consist of hard gray, overlain by a red gneiss. Lenticular deposits of quartz occur in the upper red gneiss, but do not continue in the gray, whilst there is also a series of veins of a more permanent character that seem to continue in depth; their general strike is between North 40° East, and North 40° West, with dip of from 30° to 45° mostly to the eastward. These veins are some-

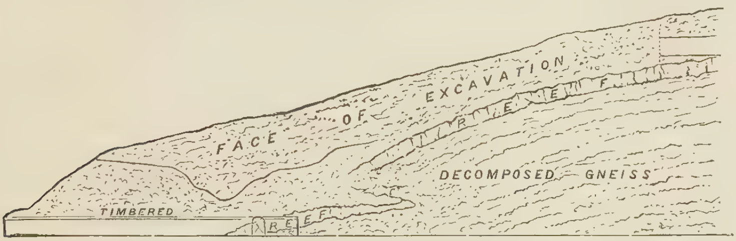


FIG. 105.—Rhodes Reef; transverse section.

times 15 to 20 feet wide; the quartz is white and glassy, the gold mostly finely divided and associated with from 2 to 5 per cent. of iron pyrites. No doubt some patches of very rich ore have been found, and these would account for native workings extending in places to the depth of 70 feet. Individual assays have given over 200 oz. to the ton, but milling upon a working scale has rarely given better results than from 3 to 5 dwts. This low average yield, in spite of occasional rich spots, sufficiently accounts for a complete collapse of the Wynaad gold mining industry, and it seems very doubtful whether the district ever presented even surface indications of sufficient importance to justify the magnitude of the operations undertaken in this region.

In the year 1802, Captain Warren, who was at that time engaged in a survey of the eastern frontier of Mysore, instituted inquiries which led to the discovery that gold washings were in operation near the village of Wurigam, the modern Urigam, or Ooregaum, and that actual mining was being carried on near

[1] A. G. Charleton, "The Indian Gold Fields," *Trans. Fed. Inst. Min. Eng.* xi. 1896, p. 345.

Marcurpam, where the quartz extracted was first pounded into dust by women and afterwards washed. The subsequent history of the gold industry of Mysore may be, to some extent, gathered from the following statements, contained in the reports of successive administrations. In 1868 it was stated that alluvial gold was occasionally found near Betmangla, but in quantities insufficient to repay the expense of collection. In 1870 it was said that at some points along the foot of the Hemagiri Hill, about sixpence per diem could be made by washing certain sands for alluvial gold. In 1872—1873 four pounds weight of gold was collected in the Betmangla taluk, and in 1873—1874 six pounds weight of that metal was obtained in Kolar. In 1874—1875 three pounds weight of gold was obtained in Kolar, besides twenty rupees' worth in the Honuali taluk of the Shimoga district; and permission was granted to a Mr. Lavelle, for three years, to prospect for gold and other metals. Leases for twenty years were, if required, to be subsequently granted for blocks of land of not more than two square miles, and not exceeding ten in number. In 1875—1876 we are told that the terms of the lease had been modified, and that prospecting was progressing, but in 1876—1877 we learn that the Urigam or Ooregaum Company had not commenced operations. In the reports for 1877—1878 and 1878—1879 there is no information relative to this subject; while in the tables relating to mines and quarries the statistics of gold and ironstone are lumped together. In the last report, however, 1879—1880, it is stated that potstone and iron ores are the only minerals now worked in the province.

The Kolar gold-field is situated in the province of Mysore, about forty miles east of Bangalore, on a vast plain covered with grass and scrub.[1] The principal formation of the district is the granitic gneiss passing into a syenitic or hornblendic variety of the same rock. A band of greenstone trap, about two miles in width, traverses the district in a north and south direction, and it is in this rock that the auriferous reefs occur.

Between this trappean formation and the gneiss to the east of it, broad bands of rock, including hornblende and mica schists occur; while it is bounded on the west by a continuous ridge of a banded ferruginous quartzose rock, rising in places to a height of over 200 feet, and towards the southern extremity of the field showing evidences of contortion. This rock has in some places a jaspery appearance, in others is composed of thin alternate laminæ

[1] Information kindly supplied by Mr. J. H. Johns of the Nine Reefs Mine.

of quartz and siliceous hæmatite, while in one or two localities a band of iron ore opens out to a width of several feet, and appears to have been at one time extensively worked. Several bands of schists, including hornblendic schist, mica schist and chloritic schist, occur between this ridge and the gneiss, and, like the shales on the eastern side, dip towards the trappean rocks. These are the rocks which, as already mentioned, have been called by Mr. Foote the Darwhar series.

The band of trap in which the auriferous reefs occur, varies in structure from coarsely crystalline diorite to fine-grained greenstone, the former appearing to pass by slow graduations into the latter. Where the crystalline structure is most fully developed, boulders of a more or less spherical form often lie scattered over the surface, or form ridges, several of which occur at various distances apart, coursing in a north and south direction. These surface boulders appear to decompose slowly, but portions of the same rock brought up from a depth of thirty or forty feet below the surface, disintegrate rapidly upon exposure, and scale off in numerous concentric coats.

The general bearing of the quartz reefs is from 4° to 10° W. of N. and they invariably occur in the fine-grained eruptive rock. Deposits of unproductive quartz, usually of very limited extent both in length and in depth, are often met with in the more coarsely crystalline variety. In the reefs occurring towards the eastern and western limits of this formation little or no pyrites has been found, but those near the centre of the mass contain a considerable proportion of mispickel; and occasionally a little iron pyrites, pyrrhotine and chalcopyrite are also met with. The walls of the reefs are often faced more or less thickly with chloritic schist, which occasionally encloses garnets. The greenstone is usually decomposed to a greater depth within a few feet of the reefs than at a more considerable distance from them, and the resulting clay, of a greenish-yellow colour, is the so-called "mullock" of Australian miners, which, when it occurs in the form of a horse, or as strings in connection with the reefs, often contains a little gold.

Some of these reefs have been worked to considerable depths over great lengths, but no records of these former workings appear to exist They have been generally worked by open-cast, but it has not been determined by what method the reefs were attacked and the water removed from the workings. Mr. Johns carefully examined a portion of a reef standing in one of the old workings in the Nine Reefs Company's property, with a view to discovering the method adopted by the former miners for breaking the rock; but although it is very hard and showed no signs of decomposition, he could neither find traces of bore-holes nor anything to indicate that borers had been employed. He, however, from time to time found pieces of charcoal in the *débris* with which the old workings were filled, and this, in the absence of any traces of bore-holes, would rather point to the ancient method of fire-setting as that by which the reef had been worked.

This gold-field has been energetically developed, and has become a highly important one, and up to 1896 may fairly be described as the only payable gold-field found in India; it is generally spoken of as the Kolar or the Mysore gold-field. The Dharwar schists are here disposed in a narrow synclinal fold, lying upon hæmatitic quartzites which vary from jaspery quartzite to schistose sandstone; this strip of folded schists lies somewhat above the general level of the gneissoid or granitoid country that surrounds it. Rich quartz veins have been developed in the Dharwar schists, and it is noticeable that the richest mines lie just to the eastward of the axis of the synclinal. The main line of reef upon which the most successful companies, such as the Mysore, Ooregum and Nundydroog, are at work, spoken of at times as the Champion reef, has been traced over 3½ miles. The reefs lying further east have been less productive, and those to the west of the axis decidedly poor.[1] The Champion reef has an average width of three feet, narrowing in some places to a mere thread and in others having exceptionally a thickness of thirteen feet; it has a general north and south strike and dips west about 45°. Numerous rich pay shoots have been proved in it, the one on which the Ooregum Mine is working having a length of a thousand feet[2] and averaging 2½ ounces of gold to the ton throughout. The total length of pay shoots proved so far is about 2½ miles; the shoots have a tendency to dip to the northwards. The reef does not preserve a uniform bearing, but is bent, contorted and folded, as well as intersected and heaved by numerous dykes of diorite and of pegmatite. The chief dyke is of basalt, 200 feet thick in places, running nearly parallel to the strike of the reefs but dipping to the east at a high angle. It intersects the Champion reef, and throws it to the west. The quartz of the Champion reef is very free from pyrites and the gold generally coarse and free. A lode parallel to the Champion and west of it, known as Matheson's reef, is, however, highly

[1] R. B. Foote, *loc. cit.*
[2] A. G. Charleton, *loc. cit.*

pyritic. Extensive ancient workings were found, chiefly upon those parts of the reefs where the gold was coarsest; some of these extended to a depth of over 300 feet. The greatest depth yet attained on this lode is in the Mysore Company's mine, being 1,520 feet in the beginning of 1896.

There are several other approximately parallel lodes such as the Oriental and the West Balaghat, upon which the gold-fields of Mysore, Limited, is working, but these seem distinctly poorer than the Champion lode, the average so far being apparently only 5 to 6 dwts. per ton. As will be seen from the subjoined tables, the average richness of the Champion lode, as developed in the workings of the leading companies, is about 1 oz. 8 dwts. to the ton.

The following tables, compiled partly from the published reports of the various mining companies and partly from statistics published from time to time by the *Mining Journal* and the *Mining World*, will serve to give an idea of the rise and progress as well as of the present importance of this gold-field:—

TABLE SHOWING AMOUNTS OF QUARTZ CRUSHED AND OF BAR GOLD OBTAINED ON THE COLAR GOLD-FIELD FROM THE COMMENCEMENT OF OPERATIONS UP TO THE END OF 1895.

Name of Company.	Quartz crushed.	Bar gold obtained.	
		Quantity.	Value.
	Tons.	Ounces.	£
Mysore	370,112	480,828	1,877,740
Ooregum	198,596	350,369	1,314,777
Nundydroog	137,083	181,547	678,504
Champion Reef	117,759	162,738	622,286
Balaghat Mysore	18,890	29,028	111,178
Minor Companies (7) . . .	32,215	13,440	51,475
Totals	874,655	1,217,950	4,655,960

The output of this gold-field in the last six years was as follows:—

Year.	Quantity crushed. Tons.		Bar gold obtained. Ounces.
1890	65,596	. . . . .	106,437
1891	72,107	. . . . .	130,328
1892	96,615	. . . . .	163,138
1893	141,118	. . . . .	206,634
1894	177,624	. . . . .	210,284
1895	213,502	. . . . .	257,223

Over ninety per cent. of the total output is the production of the four leading companies, whose returns were as follows for the year 1895:—

Company.	Quartz crushed.	Tailings treated.	Bar gold obtained.	Value.
	Tons.	Tons.	Ounces.	£
Mysore	60,654	56,662	69,487	270,911
Ooregum	53,420	56,945	70,349	263,462
Nundydroog	32,975	7,775	38,923	144,080
Champion Reef . . .	52,545	13,660	70,963	271,530
Totals	199,594	135,042	249,722	949,983

Gold occurs in Hyderabad, or the Nizam's Dominions, and mention of it is found in various works published about the beginning of the present century. Within the province of Orissa gold-washing has been carried on in the Native States of Dhenkanal, Keonjhar, Pal Lahara, and Talchir; but as is the case in many other parts of India, it is on the whole an unremunerative business. In Bengal small quantities of gold are disseminated in the sands of the streams in the Midnapur and Bankura districts, as well as in those of the Chutia Nagpur province, which includes the greater portion of the hilly region on the south-west frontier of Bengal. The localities in the Manbhum district in which gold-bearing sands are known to exist, are very numerous, and in its more northern portion there are probably but few streams of which the sands are not to some extent auriferous. By a systematic application of the operations of two gold-washers for a period extending over three months, Professor Ball[1] was enabled to define the area in which gold is comparatively most abundant. The results thus obtained were found not only to agree with the traditional information of the gold-washers, but they also very conclusively showed that the area over which the largest amount of gold is disseminated corresponds with a tract comprehending a particular series of stratified rocks. These, which consist chiefly of mica schists and quartzites, are all included in the sub-metamorphic series. Although, however, more gold was collected from superficial deposits within this area than elsewhere, those portions of the district in which metamorphic rocks are alone present did

[1] *Manual of the Geology of India*, part iii. 1881, p. 190.

not prove entirely barren. The boundary between these two formations coincides with a line drawn from Simlapal on the east, through Bara Bazaar, to a point a little north of Ichagarh on the west, and thence continued into the Chutia Nagpur highlands. South of this line sub-metamorphic rocks almost entirely prevail, while beyond the Manbhum frontier they extend into Singhbhum and Lohardaga. During the period of three months before referred to, a diary was kept in which a record was entered of the amount of gold obtained daily, as well as of the character of the rocks where the different washings were made.

An analysis of these several records shows that in the sub-metamorphic rocks the average amount of gold daily collected was 0·4 grain, while in the metamorphic rocks it was only 0·16 grain. With respect to this very small yield of gold Mr. Ball remarks that the washers were often working on strange ground, and that moreover they had frequently to walk a distance of some miles to the point at which their operations were to commence. To the above must also be added the fact that, their day's pay being assured to them, they contented themselves with a very limited amount of physical exertion. In Singhbhum gold occurs under nearly the same conditions as in Manbhum, except that in the former district it would appear to be entirely confined to the sub-metamorphic rocks. In Singhbhum quartz veins are abundant in certain shales and slates to the north and west of Chaibassa, and it is not improbable that some of these may be auriferous. In the State of Jashpur the gold-washers find it more profitable to work the ancient alluviums of the valleys than to wash the more recent sands and gravels of the streams. At some distance from its banks, and on both sides of the river Ebe, there are tracts which have been completely honeycombed with shafts of from 10 to 30 feet in depth by successive generations of gold-seekers. In the Udepur State the gold-seekers work in pits similar to those on the banks of the river Ebe in Jashpur, and the average amount of gold daily collected by each washer is stated to be about three grains.

Out of the four divisions under which the Central Provinces are classified the Narbada division is the only one which returns no gold-washers. The other divisions contribute as follows: Nagpur 139, Jabalpur 52, and Chatisgarh 12.

One of the most recent compilations[1] on this subject, after an

[1] W. King and T. A. Pope, *Gold, Copper, and Lead in Chota Nagpur*, 1891, p. 91.

exhaustive review of the history of gold-washing in Chota Nagpur, lays down the following conclusions:—

"1. The Southern half of the Chota Nagpur province is certainly an alluvial gold tract.

"2. The Northern portion is only very locally so.

"3. The proper alluvial auriferous tract is confined to the great area of transition rocks.

"4. The more special restriction of auriferous washing to the transition tracts shows that gold must have been derived from matrices in the transition tract, whether from the country rock itself or from veins or reefs in it."

The transition rocks of the Dharwar series are in many places in this province traversed by irregular veins, veinlets or bunches of quartz, which seem occasionally to be auriferous. Between 1890 and 1892, a number of companies were formed to work these, chiefly in the Sonapet district, but in every case with disastrous failure. Most of them commenced work on narrow bedded and irregular fissure veins of quartz running in micaceous and hornblendic schists and other metamorphic rocks. The strike of the veins was generally east and west, with a steep dip to the south; the quartz was at times mineralised by small quantities of iron pyrites, arsenical pyrites and galena, and occasionally gave assays of a few pennyweights of gold, especially near the surface. Quartz showing free gold was also said to have been met with. It is very doubtful if anything more than a few ounces of gold was ever obtained from the entire district, and the general appearance of the deposits was unpromising in the extreme. It is, however, rumoured in 1896 that a payable reef has been found in Chota Nagpur. The alluvial gold of the district is extremely poor and in very small quantity, only suitable for working on the smallest scale by the natives, none of whom seem to subsist by gold-washing alone. The gold is generally exceedingly fine, although it is said that fair-sized pieces have exceptionally been met with. The whole district is everywhere covered with quartz *débris* in immense quantity; it is usually white, stony, and quite barren of gold.

It is stated that in Rajputana gold dust was formerly obtained from the sands of the Luni and Khari rivers, but gold-washing appears to be no longer carried on in that country.

In the Presidency of Bombay the districts of Dharwar, Belgaum, and Kaladgi, in the Southern Mahratta country, with the province of Kattywar, include all the known gold-bearing rocks. Mr. R. B.

Foote,[1] of the Geological Survey, regards the metamorphic rocks of the gold-bearing areas of the Dharwar district as belonging to three distinct groups, each characterised by specific lithological peculiarities. These he distinguishes as the Dhoni, Kappatgode, and Surtur groups.

The Dhoni group is composed of hæmatitic, hornblendic, chloritic and micaceous schists, with which are associated several beds of white and grayish limestone. Above this comes the Kappatgode group, consisting of hæmatitic and argillaceous schists, which are frequently mottled, but of which the prevailing colours are white or reddish buff. The third, or Surtur group, is made up of hornblendic and chloritic schists associated with massive dolerite. Quartz veins occur throughout these groups, but according to the native washers auriferous sands are found only in streams rising in the Surtur series.

In the Surtur group the outcrops of the quartz reefs, which usually run parallel with the bedding, have generally been more or less broken up by gold seekers; in the other groups the quartz veins often course across the strata. The Hati Kati Reef is in the Kappatgode series, and in its *débris* Mr. Foote found traces of visible gold. This reef contains iron pyrites, besides other sulphides, and it has, to some extent, been opened at the outcrop by rude sinkings and shallow trenches indicative of native mining.

It has been stated that all the rivers of the Punjab, the Ravi alone excepted, contain auriferous sands, and although this may not be literally correct, it is still an undoubted fact that the rivers and streams of this province do, as a general rule, contain gold. This is equally true with regard to those rising in distant ranges of crystalline rocks, as well as of those having their sources in lower detrital hills of Tertiary age. The practice of gold-washing is in the Punjab doubtless of considerable antiquity, and under the Sikh Government the taxes upon this industry amounted to one-fourth of the gross produce. Now, however, as in most other parts of India, the income from this source has either dwindled to very small proportions or has become entirely extinct. The districts of the Punjab in which gold occurs are Bannu, Peshawur, Hazara, Rawalpindi, Jhilam, Amballa, and certain Native States.

Assam has long been famous for its production of gold, and it has been stated by various authors that all its rivers contain gold-bearing sand; some, however, limit this general statement to those

[1] *Records Geol. Surv. Ind.*, viii. 1874, p. 133; *Mem. Geo. Surv. Ind.* xii. 1876, p. 259.

which rise in the northern hills. It would, however, appear that there are few streams in the districts of Darrang, Sibsagar, and Lakhimpur which do not yield gold. A large proportion of the gold obtained in Assam is apparently derived from the degradation of rocks of Tertiary age; that, however, which is found in the upper reaches of the Brahmaputra probably comes directly from the crystalline rocks.

Within the limits of British Burma gold has been found in the beds of the Irawadi and some of its tributaries, in the Pegu division, and in the beds of the Sittang and its tributaries. The Tavoy river and the Great Tenasserim and its tributaries in the Tenasserim division, also contain auriferous sands, but gold-washing would appear to be by no means a remunerative business. In the Upper Irawadi at Bhamo and near Thingadhaw, gold is obtained from auriferous sands. Some miles nearly due south of the last locality is a small rivulet the sands of which are auriferous, and where, it is stated, each washer could earn the equivalent of three shillings a day. A few miles nearer Thingadhaw the Ponnah creek contains gold, but the washers are described as being miserably poor. Quartz mining has recently been started by an English Company at the Choutupazat Mine near Nankan in Upper Burma.

Silver.—Although the natives of some parts of India were able long ago to separate gold from silver, and to extract the latter metal from argentiferous galena, there appears to be no direct evidence that silver was ever largely produced in the country. The extraction of silver from argentiferous galena is probably still practised in Kandahar and Kashmir, but the only region in which this industry is regularly carried on is in the Shan States which are tributary to Siam. Specimens of silver ore and even of native silver are stated to have been found in many parts of India, but the quantity has always been exceedingly small, and in many cases further evidence of its occurrence in the localities indicated would be desirable. It follows that any silver which may have been hitherto found in India otherwise than in association with galena, is of greater mineralogical interest than commercial importance.

Lead.—At the present time lead is produced in British India in very small quantities only, although there is probably no metal, with the exception of iron, of which the ores were formerly so extensively worked. Evidence of this is afforded by the extent of the ancient lead mines of Southern India, Rajputana, Balochistan, and Afghanistan. According to Mr. George Watt,[1] "Lead mining in India may be said to be at present practically in a dormant condition."

In the Presidency of Madras lead ores have been found; in Kadapah, at Jungumrazpilly and Cotelur; in Karnul, at Gazalpully and Koilkontla; in Bellary, in the Sandur Hills; and in Palnad at Karampudi. Mr. King describes the Jungumrazpilly mines as follows: "The old and now deserted lead workings are at the south end and east side of the low ridge, just north-north-east of the village. The pits or galleries have been excavated between beds of dark gray siliceous limestone which is impregnated with strings of white and dull blue quartz. These rocks are referred to the Cumbum division of the Nallamallay group of the Karnul series. Granular sulphide of lead is disseminated in very small quantities through the blue quartz. In the white quartz there are faint traces of copper. The strings of quartz have been deposited in north-north-east and south-south-west fissures, having a dip of 60° westward, the strata lying at 50° E. by N. The old workings are to a great extent filled up with the excavated fragments of rock and are now overgrown with jungle."[2] Lead ores from this locality contain from $10\frac{1}{2}$ to $13\frac{1}{2}$ oz. of silver per ton. The origin of these extensive excavations is lost in obscurity, although it is known that the mines were wrought by the Hindu kings of Bijanagar, and subsequently by the Mohammedan nawabs of Kadapah in the time of Halim Khan. They were afterwards worked by Hyder and Tipu, the latter of whom is said to have destroyed all documents relating to them.

In Bengal, within the limits of the Bhagalpur division, lead ores have been found in the Sontal Parganas district at or near the following localities: Sankera Hills, Tiur Hill, Bairuki, and at Panch-Pahar or Akasee.

In the Province of Chutia Nagpur lead ores have been found in Manbhum at Dhadka; in Hazaribagh at Mahabagh, Baragunda, Mehandadi, Barhamasia, Nawada, Khesmi, Mukundganj, Parşeya and Hisatu; in Lohardaga at Barikhap and Sili; in Sirguja at Bhelounda and Chiraikund. In all these places the rocks in which the veins occur belong to the metamorphic series. At Dhadka in the Manbhum district in a hill of mica schist close to a village called Jani Jor, near an outlying house belonging to the village of Dekia, a deposit of galena was discovered in 1869 by

[1] *Review of Mineral Production in India for* 1894, p. 22.
[2] *Mem. Geol. Surv. Ind.* viii. 1872, p. 273.

some Kumars when searching for iron ore. The galena from this locality contains from 60 to 80 oz. of silver per ton of ore, and occurs in lenticular masses associated with hæmatite and quartz in a true lode. Messrs. King and Pope (*op. cit.*), writing in 1891, can say nothing more definite than that the evidence respecting the occurrence of lead and copper in Chota Nagpur, "is strongly in favour of a presumable workable development in many places." Lead ore from Hisatu is first mentioned in a letter addressed to Warren Hastings and the Council, dated Calcutta, 1777. At the present time the old excavations and *débris* so obscure the outcrop at this place, that without making fresh openings it would be impossible to form any opinion as to the precise nature of the deposit. The neighbouring rocks are gneiss with hornblendic and micaceous schists.

In the Central Provinces lead ores have been found in Sambalpur at Talpuchia, Jhunan, and Padampur; in Raipur at Chicholi; in Nagpur at Nimbha; in Jabalpur at Sleemanabad, and in Hoshangabad at Joga. With but two exceptions these deposits occur in metamorphic rocks; the exceptions being Padampur, where the country rock is a limestone belonging to the Vindhyan series, and Joga, where galena occurs in limestone of lower transition age. The existence of galena on the banks of the Mahanadi, near Jhunan in the Sambalpur district, was known by local tradition, but the exact spot where it occurs was not discovered until 1874, when by cutting trenches at right angles to the granitic rocks a lode containing that mineral was discovered. The lode, where opened upon, was from 16 to 19 inches in width, the veinstone was principally composed of quartz, and the galena obtained from it yielded lead containing 12 oz. 5 dwt. of silver per ton. In the year 1875 a cutting was made with a view of tracing this lode inland from the banks of the river, but there being no one on the spot capable of carrying on the operations, the alluvial covering was not sufficiently removed to determine whether the lode was continuous or otherwise. In the year 1868 a discovery of galena was made by some stone-breakers who were employed in preparing road metal, about three miles west of Chicholi in the Raipur district. Specimens of galena subsequently examined contained about 10 oz. of silver per ton of lead. The locality was visited by Mr. W. T. Blanford[1] in 1870, who describes the ore as occurring in a true vein, largely composed of quartz, traversing granite or granitoid gneiss and hornblende schist passing

[1] *Records Geol. Surv. Ind.* iii. 1870, p. 44.

into diorite. In addition to quartz the vein contains pink felspar, green and purple fluor spar, epidote, and traces of the carbonates of copper. The galena is thinly disseminated through the veinstone, but Mr. Blanford, on the whole, did not consider the indications unfavourable.

Galena occurs in Ajmir, Alwar and Udepur in Rajputana, and has been mined for somewhat extensively at the foot of the Taragarh Hill, close to the city of Ajmir, the other localities being of less importance. The mines, of which considerable traces still exist, were at one time farmed by the Mahrattas, and it is stated that their suspension was due to the Mutiny and the desire of the Government to prevent the extraction of lead which might be used for the manufacture of bullets. According to Mr. Hacket[1] the ore occurs in a number of approximately parallel veins, traversing a quartzite of sub-metamorphic or upper transition age in nearly the same direction as the strike of the rocks. The galleries followed the courses of these veins, and were only sufficiently large to allow of the miners crawling through them. The ores were brought to the surface in baskets, which were passed from hand to hand by a number of coolies seated within reaching distance from one another. A considerable discrepancy exists in accounts relative to the amount of lead produced at these mines. In 1830, Captain Dixon placed it at only 42 tons 10 cwts. per annum ; on the other hand, it is stated in the local gazetteer, as well as in the Settlement report, that about the year 1818 their annual production was from 340 to 400 tons of metallic lead. None of the accounts of these mines mention silver as occurring in the ores. In 1846 the Ajmir magazine ceased to receive the metal produced, and the mines were consequently abandoned.

In Bombay galena occurs in Jubhan, and at Khandelav Lake in the Panch Mahals district in Gujarat. The galena contains about five ounces of silver to the ton of ore. No attempt to work these mines has been made since 1874.

In Balochistan there are ancient lead mines at Sekran, but they are now deserted. These mines are described as having been very extensive, and it is stated that they formerly employed 200 men. The vast quantities of slag found in the district testify to the once great extent of the industry.

In the Punjab Himalayas there are a number of localities, especially in the Kulu and Simla districts and in the Sirmur State, where lead ores occur, which, in some cases, have been worked

[1] *Records Geol. Surv. Ind.* xiii. 1880, p. 247.

on a very limited scale. In the Simla district galena occurs on the east bank of a stream near the village of Chapla, where the vein runs parallel to the bedding of the rocks, which are slates intercalated with thin beds of limestone. Mining and smelting were for some time carried on in this locality under European management, but as all operations have now ceased, it may be concluded that the undertaking was not a profitable one. On the banks of the Tons river, about twenty-five miles above Kalsi, is a tract of country surrounding Swinj, partly included in Sirmur and partly in Jaunsar, where lead mining has been somewhat extensively carried on. Mr. H. B. Medlicott, who visited this locality in 1862, says that only one mine was then open. He describes the lode as being about two feet in width, well defined, and with a dip at an angle of 70° towards east-north-east. The galena exists chiefly in the form of a regular leader near the foot wall; there is, however, another distinct band, consisting chiefly of quartz, containing blende, galena and iron pyrites. The rocks in which this vein is enclosed consist of slates and limestones of the Krol and Infra-Krol groups.

Within the limits of Assam there appears to be no record of any discovery of lead ore, but there is undoubted ground for believing that considerable deposits must exist at no great distance beyond its frontiers. Lead ores occur in numerous localities in British Burma, but little is known either of the nature or the extent of the deposits. Native Burma and the surrounding States are believed to produce large quantities of lead. In Tenasserim lead ore is said to occur in limestone of Carboniferous age. The exact character of these deposits does not appear to have been placed on record, but there would seem to have been some crude attempts made to work a few of them. It must not be forgotten that in semi-civilised countries with but imperfect means of communication, it is, as a rule, only deposits of the precious metals that can be worked with profit by Europeans, and that are consequently sought for, because the relatively high cost of freight in the case of the commoner metals would mostly prove prohibitive, however rich the deposit itself might be.

Copper.—The copper ores of Peninsular India occur in the older crystalline or metamorphic rocks, as well as in various groups of transition age. In Extra-Peninsular India they are found, for the most part, in highly metamorphosed rocks, the precise relations of which to those of the Peninsula have not in all cases been determined. As a rule, to which there are but few exceptions, the copper ores of India do not occur in true lodes, but are either sparsely disseminated through the rocks which contain them or are locally concentrated in patches and bunches; occasionally also fissures have by infiltration become filled with ores, and veins on a small scale have thus been produced. Both in the Peninsular and Extra-Peninsular regions there are ancient mines of great extent whose history is lost in remote antiquity, but working for copper ores is now carried on only on the most limited scale.

In the Madras Presidency traces of copper in greater or less abundance are found in Trichinopoli, Bellary, Kadapah, Karnul and Nellore. Some of the most extensive copper mines of this part of India are situated in the Nellore district, in the vicinity of the villages of Gunnipenta and Yerrapilly. The natives of the locality attribute the working of the earliest mines to the kings of Bijanagar; and after the fall of the Hindu empire in 1564 it is believed that the Mogul conquerors and the agents of Tipu and Hyder successively carried on mining operations. The excavations are described as being of great magnitude, and extensive mounds of copper slags testify to the fact of large quantities of ore having been smelted upon the spot. The principal ancient mines are thirty miles north of Yerrapilly, in the neighbourhood of Gorganpully; they are said to be 100 feet in depth, and to extend over a length of several hundred feet. The Nawab of the Carnatic is stated to have worked mines in the Venkatagiri taluk previous to the year 1780, and that they were only given up on the assumption of the country by the British. The first attempt to work the mines of this locality by Europeans was made in 1803, since which time operations have at various periods been resumed, but on each occasion the workings resulted in pecuniary loss. The information which is possessed relative to the nature and extent of these deposits is far from complete, although it is certain that very rich copper ores have been obtained from the mines.

In Bengal at Bairuki, in the Deoghur district, copper ore was discovered by a native in the year 1849. The report of this discovery created at the time a good deal of excitement, although it does not appear that a company for working the mine was ever formed. Mr. Barratt, an English mine agent, however, reported favourably on the property, stating that the ore occurred in a champion lode 9 feet thick. In the Singhbhum district, and in the State of Dhalbhum, are probably the most widely extended copper deposits known in Peninsular India. Traces of copper ores usually marked by the presence of ancient excavations here extend at intervals over a distance of about seventy-six miles. The copper ores appear to exist on a well-defined horizon close to the base of the transition system of rocks. As a rule the ores are disseminated through bands of schist, the dip of which corresponds to that of the adjacent strata; in some places, however, they would seem to occur in more or less regular veins. Indications exist of mining and smelting having been carried on in this region from a very early period, the available evidence pointing to the Seraks as being probably the first to inaugurate working in this locality. The number and extent of the ancient workings testify to the assiduity with which every trace of ore was followed both by the early pioneers and subsequently by those who succeeded them in more recent times. Mining under European management was commenced at Landu and Jamjura in 1857, and for a short period from 60 to 65 tons weight of copper ore were turned out monthly, but either from injudicious expenditure, or through the poverty of the deposit, operations were abandoned in 1859.

Mining in this district was resumed at Rakka[1] in 1891; a shaft was sunk to a depth of 248 feet, and passed through two beds of workable copper ore. The upper bed was about 2 feet thick, and consisted of quartzite, heavily charged with copper pyrites; the other one, some 50 feet below the former, was about 3 feet in thickness, and showed a central band some eight inches in thickness of almost solid copper pyrites. In addition, the formation—chloritic schist with strings of quartz—was impregnated with the same mineral for a thickness, as proved by cross cuts, of 359 feet. The general strike of the beds is east and west, and their dip 45° to the north.

The excavations which mark the position of the ancient workings at Baragunda in the Hazaribagh district are situated along a line of outcrop of metamorphic rocks, which form a ridge three-fourths of a mile long between the villages of Parsabera and Baragunda. These rocks consist of quartzite and granulite gradually passing into gneiss, associated with micaceous, talcose and hornblendic schists. The excavations at this place are very extensive, but nothing is known either as to their date or origin. Although some of the specimens obtained from this locality show that it many cases the ore occurs as a constituent of the schists,

[1] Robert Oates, "The Copper and Tin Deposits of Chota Nagpore," *Trans Fed. Inst. Min. Eng.* ix. 1894, p. 427.

others would apparently indicate the presence of deposits parallel to the bedding. Dr. McClelland mentions the occurrence of large quantities of copper slags, covering several acres of ground, at the village of Giridi, about two miles distant from the mines, where, in the vicinity of fuel and water, the ores were evidently smelted.

Work was recommenced at Baragunda[1] in 1882, but stopped again in 1891, when the existence of a bed of mica schist, full of garnets, and so impregnated with copper pyrites as to assay 1 per cent. of copper, was ascertained. The bed varies from 7 to 22 feet in thickness, averaging about 14 feet. Galena and zinc blende in small quantities are also found in it.

In the Central Provinces copper ores are known to exist in Raipur, at Chicholi; in Jabalpur, at Sleemanabad; Narsinghpur, at the Birman Ghât; and in Chanda, near Thana Wasa. At the Birman Ghât, in the Narsinghpur district, copper ores were discovered in the year 1873 on a small island in the bed of the Narbada river. Mining operations were commenced shortly afterwards, and a parcel of ore which was sent to England for sale is reported to have paid its expenses. Shortly after the ground was first opened the band of metalliferous rock was stated to have a thickness of six feet. The results of subsequent operations are not recorded, but the mine was ultimately abandoned.

Copper ores are found in several of the independent States of Rajputana, as well as in the British district of Ajmir. In these regions mining was formerly carried on upon a very extensive scale, but at present the business of the miner has become all but extinct, since operations are carried on in but few localities, and always upon the most limited scale. Mines occur in the States of Alwar, Bhartpur, Jaipur, Udepur, Bundi and Bikanir. At Daribo, in the Alwar State, there are mines situated on a sharp anticlinal curve in a thin band of black slates intercalated in quartzites. There appears to be no true lode at this place, and the ore, which is copper pyrites mixed with mispickel, occurs irregularly disseminated through nearly black slates, nests of ore being also occasionally met with. The ore, as is usual in the native process, is pounded, made into balls with cow-dung, roasted, smelted with charcoal, and afterwards refined in an open fire. During some twelve years the average annual yield from this locality only amounted to 3 tons 8 cwts., and this, owing to the influx of

[1] Robert Oates, "The Copper and Tin Deposits of Chota Nagpore," *Trans. Fed. Inst. Min. Eng.* ix. 1894, p. 427.

European copper, is gradually diminishing. Small quantities of the sulphates of copper and iron are obtained by washing the mine refuse. At Singhana, in the Jaipur State, the mines are described as consisting of tortuous galleries of great extent. At the working face fires were lit, which caused the rock to split up, and the loosened fragments were subsequently detached by the aid of wedges. The principal entrance to the mine is by a gallery driven into a ridge of quartzite in the direction of its strike, and at a point several hundred feet above the level of the plain. This gallery is sometimes 60 feet in width, is of considerable height, and from it three separate galleries strike off into the hill. In these there is scarcely a trace of ore remaining, and all the ends are concealed by fallen *débris* or by accumulations of water. These mines have long since been abandoned on account of their general poverty, but considerable quantities of blue vitriol, alum, and copperas are still manufactured from decomposed slate and other refuse from the old workings. At Khetri there are workings very similar to those of Singhana. The ores are here sold by auction to Mohammedan merchants, by whom they are smelted in small blast furnaces blown by hand bellows; the manufacture of blue vitriol, copperas, and alum is actively carried on at these mines.

According to Mr. Ball, there is no authentic information with regard to the existence of copper mines either in Bombay or in Balochistan, but in Afghanistan a copper-producing district is known to exist between Kabul and Kuram. In the Punjab, copper deposits are by no means numerous, and none of them possess any particular importance.

In the North-West Provinces, the districts of Kumaun and Garhwal have long attracted attention through their copper mines. These were first examined by a Cornish miner so long ago as 1838, and were subsequently worked at various times until the year 1855, when they were visited by Mr. W. J. Henwood, who came to India for the purpose of examining and reporting upon the metalliferous deposits of Kumaun and Garhwal. Mr. Henwood's report deals principally with the iron ores of the country, but he also devotes several pages to copper deposits, with which he was not, on the whole, favourably impressed.

The district in which the Sira mines are situated consists, for the most part, of clay slate, in which traces of copper are numerous. Several neighbouring deposits have from time to time been examined, but mining operations of any extent have been confined to one only, in which copper ores occur in a stratum parallel to the bedding of the adjoining rocks. The ore-producing floor is from two to three feet in thickness, but is at intervals enlarged by the falling into it of metalliferous strings of quartz. Its principal constituents are quartz and talc, but the former, frequently mixed with a little calcite, is by far the more abundant ingredient. Although sometimes accompanied by iron pyrites, chalcopyrite is the most plentiful ore, and occurs in the form of short narrow veins, small bunches, and scattered granules. In the richest portions of the deposit it is, however, very thinly distributed throughout the matrix.

The Danda Mine is situated near the top of a rugged and precipitous mountain, the ridge of which is talcose slate, and the

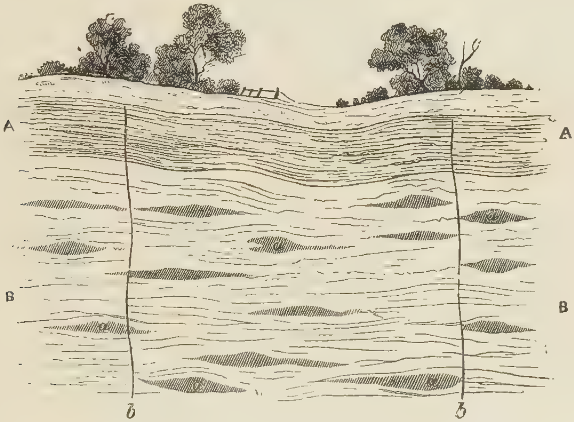


FIG. 106.—Danda Mine ; section.

middle chloritic slate, while the base is composed of a mixture of the two rocks in thin alternate layers. The chloritic slate is at intervals interstratified with thin lenticular beds of quartz, few of which exceed three feet in length or are more than six inches in thickness. Occasionally chlorite is, to some extent, diffused through this quartz, which is also sparingly mingled with iron pyrites and chalcopyrite. Fig. 106, after Mr. W. J. Henwood, represents a section at the Danda Mine, in which A is talcose slate, B chloritic slate, *a* the metalliferous quartz, and *b* joints.

At Dhanpur or Dhunpoore the slate rock of the neighbourhood, which is generally blue, although sometimes buff or brownish in colour, has usually a silky lustre, and is much contorted by the intercalation of thin crooked and irregular beds of quartz.

The quartz is almost invariably associated with a small proportion of calcite. A bed of siliceous limestone, of which the prevailing colour is a pale buff, and which, though slightly undulating, may be regarded as nearly horizontal, is usually about one foot in thickness, but occasionally enlarges to fifteen or even twenty feet. The slate and limestone are both traversed by two sets of joints; one nearly parallel to the strike, and bearing E. and W., and the other between N. and S. and 10° to 15° E. of N. and W. of S. Each series is highly inclined, and in both dip and bearing is subject to frequent but inconsiderable flexures. In the majority of cases these joints exhibit mere contact surfaces; sometimes, however, they enclose laminæ of the adjoining rock, or plates of erubescite, while in others they contain a mixture of copper ore and country rock. The non-metalliferous material thus included is divided into approximately lenticular masses by the reticulation of numerous small joints, which are often faced with clay. At these intersections the surfaces of the lenticules of sterile matter, as well as those of the ore itself, are often marked by slickensides. A third set of joints, which bears about 30° E. of S. and W. of N., is but imperfectly developed. The joints of both the principal series widen, and become more metalliferous, in proportion as they approach the nearly horizontal bed of siliceous limestone, and then sometimes attain a thickness of above six inches. These characteristic deposits of ore do not, however, occur when the two systems of transverse joints and the nearly perpendicular ones merely intersect one another, but at those points only where the intersections come in contact with the upper surface of the bed of limestone.

The rock in the vicinity of these double intersections is often for some distance richly charged with nests of erubescite and copper pyrites, from which veins branch off and penetrate both the limestone and the adjoining slate. In extreme cases this impregnation of the rocks extends for a distance of from twenty-five to thirty feet, but generally for less than half that distance. Fig. 51 page 154 after Henwood, shows the mode of occurrence of copper ores in the rock joints at this mine. The report of Mr. Henwood on the Chaumattiya Mine clearly indicates the general mode of occurrence of copper ores throughout the region. He says: "There is no *lode* or metalliferous *vein* visible in it, nor have we seen one during our inquiries in this country."[1]

The existence of copper ores in Darjiling was first discovered

[1] *Selections from Records, Government of India*, viii. 1855, p. 4.

in 1854, since which time its occurrence in various parts of the district has been established. A mine which was opened about 1870 at Mangphu, on the Tista, is considered the best in Darjiling, and is believed to be the only one at present in operation. The rock is a light green slate, containing irregular layers of slaty sandstone. The ore, with which there is but little iron pyrites, occurs in both rocks, in the form of lenticular beds. The cupriferous layers occur at intervals throughout a total thickness of 200 feet, and openings have been made upon them at various levels.

No copper ores have hitherto been discovered either in Assam or in British Burma. In Tenasserim specimens of an ore containing copper were obtained in 1863 at a point on the Yoonzalem river; some copper slags were also found in three different localities; but at the present time no copper industry of any kind is carried on in the country. The latest statistics [1] obtainable are for 1891, when Bengal is said to have produced 2,500 tons (of ore?). In 1888, 218 tons of refined copper were turned out. The industry of copper smelting has been stagnant in India for many years, and has only been resumed to a limited extent in Bengal.

TIN, &c.—Tinstone has been rarely found within the limits of Peninsular India, and the only localities in Extra-Peninsular India where it occurs in any considerable quantities are situated in the Tenasserim division of British Burma.

In the Bengal Presidency tin oxide occurs at Nurunga, and is described as forming lenticular beds in gneiss, which are seldom above one foot in width, but are sometimes as much as sixty feet in length. About fifteen years ago from 8 to 9 cwts. of metallic tin were obtained from ore mined at this place. It was re-opened in 1891,[2] when an incline shaft was carried down to a depth of 600 feet. Several beds of soft gneiss, dipping about 30° to the east, having a harder bed for roof and a layer of fluccan for floor, were proved, the most important one varying from 1 foot to 3 feet in thickness. In addition to tinstone these beds contain veinlets of felspar, black mica, and crystals of magnetite, the proportion of tin ore varying between 3·6 and 13 per cent. Too little work has been done to form any accurate conclusions respecting this deposit, but from the somewhat anomalous mode of occurrence of tinstone in a bed and the absence of such minerals

[1] *Review of Mineral Production in India for* 1894, p. 20.

[2] Robert Oates, "The Copper and Tin Deposits of Chota Nagpore," *Trans. Fed. Inst. Min. Eng.* ix. 1894, p. 427.

as tourmaline, wolfram, &c., with which it is usually associated, the guess may be hazarded that it is simply an ancient bed of alluvial tin ore, subsequently metamorphosed into gneiss. Work was stopped in 1892, after nothing more than prospecting had been done; the formation was, however, proved to extend over a large area, as well as to hold in depth.

In Bombay a few specimens of cassiterite of mineralogical interest only have occasionally been obtained, but as yet there is no reason for supposing that it occurs in quantities possessing any commercial importance.

Tin ore is found in various localities in the Tenasserim division of British Burma, and is collected chiefly by Chinese labour from sands and other alluvial deposits. About the year 1873 the township of Ma-lee-won was leased to Messrs. Steel & Co., a firm of Rangoon merchants, with a view to working for tin upon a large scale. In addition to an abundant supply of stream tin, various rich tin lodes were said to have been discovered. During the year 1874—1875 machinery was erected, roads opened out, and a parcel of ore prepared, which yielded about seven tons of metallic tin. As, however, the outlay had very largely exceeded the returns, the lease was abandoned in 1877.

It would seem that this result was the fault of the system of working adopted. Mr. Hughes,[1] who inspected the district in 1889, has no doubt of the abundance of tin ore in deposits practically identical with those of the Malay peninsula, of which latter the former are no doubt the continuation. He found numerous mines in operation, owned and worked by Chinese and Siamese, the tin-bearing sands being as much as 12 feet thick in places. He gives no statistics of production, which is given as 98 tons in 1894.

So far as is yet known, zinc ores are of rare occurrence in Peninsular India, but in some of the Southern Provinces blende and calamine are described as being somewhat more abundant. In Rajputana there is at least one mine which is reported to have been formerly worked for ores of zinc.

Cobalt ores in small quantities are found in some of the mines of Rajputana, and are used for the purpose of colouring glass bangles; ores of this metal also occur in Tenasserim. Both cobalt and nickel are present in small quantities in the pyrrhotine from the Khetri Mines, and traces of nickel sometimes occur in

[1] T. W. Hughes-Hughes, "Tin Mining in Mergui District," *Geol. Survey of India Records*, xxii. 1889, p. 188.

iron ores from Bhangarh. Ores of manganese have been found in various localities, and some of the Indian iron ores contain a certain amount of that metal. Manganiferous hæmatite and nests and veinlets of psilomelane occur at Jabalpur; the deposits seem to be beds or perhaps bedded veins. Similar deposits of pyrolusite occur at Gosalpur in the same district. The Madras Presidency is said to have produced 11,410 tons of manganese ores during 1894.

Iron.—Iron ores are so plentiful over large areas in British India, that it would be impossible within the limits of the present notice to give even the names of the various localities in which they are known to be abundant. In order, therefore, to convey an idea of their abundance and extent, it will be convenient, in the first place, to give a concise account of their mode of occurrence and distribution in rocks of various ages, and, subsequently a short description of a few of the most important deposits hitherto discovered. In Peninsular India the magnetic oxide occurs either in beds or veins in almost every region in which metamorphic rocks prevail; while in certain localities, as in the Salem district in the Madras Presidency, the development of magnetite is on a scale of extraordinary magnitude, whole ranges being composed of this mineral in its purest condition. In many cases these deposits would appear not to be in the form of veins, but to occur as beds, in the same way as do the gneissoid and schistose rocks with which they are associated. In the Chanda district enormous deposits of specular iron ore and magnetite occur under similar circumstances. Mr. Ball remarks with regard to the iron ores of India: "To the abundance and wide-spread distribution of these ores in the oldest rocks is no doubt to be attributed the fact of the frequent recurrence of considerable deposits, and the general dissemination of ferruginous matter, which more or less characterise the sedimentary rocks of all subsequent periods." [1]

Bedded magnetite is likewise known to occur in the sub-metamorphic or transition rocks; while, both in the metamorphic and sub-metamorphic series, considerable veins of limonite are found in fissures and along lines of fault. Examples of such deposits occur in Kadapah, Karnul, Manbhum, Jabalpur, &c., &c.; but the rich ores of Central India occur principally as hæmatites, in rocks belonging to the lower transition series.

In the Gondwana system of rocks, although many of the conglomerates, sandstones, and shales of the Barakar group are almost

[1] *Geology of India*, iii. p. 335.

free from iron, others enclose concretionary masses of limonite, while in some of the coal-fields bedded clay ironstone occurs in sufficient quantity to render them of considerable importance. It is believed that in all the coal-fields these ores, whether of a concretionary or bedded character, are used by the native smelters, but they invariably select the unaltered carbonates only, as they regard ores which have been partially transformed into limonite as unsuitable for reduction. The so-called Ironstone Shales are not represented beyond the limits of the Damuda Valley, and as a source of iron ore their development is at its maximum in the Raniganj coal-field, where there is an inexhaustible supply of readily accessible ore. This mineral, which originally existed either as blackband or as clay ironstone, has, near the surface, been to some extent altered into limonite. In the Raniganj-Kamthi group the distribution of iron ore is very unequal, since in the typical Raniganj rocks ferruginous matter is often almost wholly absent; while in their western equivalent, the Kamthi group, there is not only much disseminated oxide of iron, but also thin layers of iron ore which are made use of by the natives for smelting purposes.

The characteristics of the succeeding groups of the Gondwana series, so far as iron ores are concerned, are almost precisely similar to those last described. The Cretaceous rocks are next in sequence in the peninsular formation. In the Trichinopoli district of Southern India, rocks of this age contain nodules of iron ore in considerable abundance, and, when fuel was locally more abundant than it is at present, they were, to some extent, smelted by the inhabitants.

The Deccan trap, which is believed to have been poured forth towards the close of the Cretaceous period, and was perhaps continued into early Tertiary times, contains large quantities of iron ore. This, to a large extent, occurs in the form of disseminated crystals of magnetite, but occasionally also either as nests or layers of hæmatite, gradually passing into bole or ferruginous clay. The beds of rivers traversing this trap contain iron sands, and these, after concentration by washing, often supply the small blast furnaces of the native iron-smelter.

Bands of iron ore, which not unfrequently occur towards the base of certain beds of laterite, are the sources of an easily-worked brown hæmatite which sometimes contains a large percentage of iron. These ores have been employed by native smelters in localities scattered over almost the whole of India, while at Bepur in Malabar, and at Mahomed Bazaar in Birbhum the same ores have been smelted at establishments under British management.

In addition to the foregoing there are detrital ores of sub-recent age, resulting from the breaking up and re-arrangement of the older deposits, as well as from other superficial accumulations of ferruginous material. These, being generally obtainable without much trouble, are frequently preferred by the natives to harder or more refractory ores.

In Extra-Peninsular India iron ores are found in considerable abundance in groups of rocks, many of which are of very different ages from those which occur within the limits of the peninsula. The principal sources of these are Tertiary rocks; but in the North-western Himalayas, and it is believed also in Afghanistan and Burma, there are considerable deposits of iron ore in the older metamorphic rocks.

In the Madras Presidency, iron ores are said to be very generally distributed throughout the Madura district, and, according to Mr. R. B. Foote,[1] ores obtained from lateritic conglomerates were formerly smelted, of which large heaps of slags scattered plentifully over the country afford evidence; the industry is, however, now extinct. In this district, a deposit of magnetic iron ore occurs in gneissic rocks about a mile north-east of the village of Mallampatti, in the Pudokotai State. Mr. Blanford,[2] in his description of the Cretaceous rocks of Trichinopoli, mentions that they frequently contain nodules of iron ore, which were formerly smelted, as is evidenced by numerous mounds of slag; but owing to the scarcity of timber the industry is now almost, if not entirely, extinct. The extent, number, and thickness of the beds of magnetic iron ores in the Salem district are among the most remarkable phenomena connected with the geology of India. Messrs. W. King and R. B. Foote, who have given an account of the distribution of these ores, have divided them into the following groups:—[3]

1st. The Godumullay group, east and north-east of Salem.
2nd. The Tullamullay-Kolymullay group.
3rd. The Singiputtay group.
4th. The Tirtamullay group.
5th. The Kumjamullay group.

On account of the persistence of these beds over long distances, they frequently afford a valuable clue to the geological structure of

1 *Records Geol. Surv. Ind.* xii. 1879, p. 147.
2 *Mem. Geol. Surv. Ind.* iv. 1865, p. 216.
3 *Ibid.*, iv. 1865, p. 58.

large areas. They, in some cases, form the culminating ridges of high ranges of hills, and are occasionally from 50 to 100 feet in thickness. Where, therefore, such beds are either vertical or steeply inclined, enormous amounts of ore are laid bare in cliffs and escarpments. The purity of this ore varies considerably, being sometimes much mixed with quartz, but ore of the best quality is, nevertheless, to be obtained in quantities which can only be estimated in thousands of millions of tons. Mr. T. H. Holland[1] re-examined this district in 1892, and corroborated the existence of enormous masses of magnetite in bedded deposits; he also drew attention to the occurrence of chromite and ilmenite. The "Porto Novo Steel and Iron Works," which, in 1833, were established in South Arcot, were, up to the time of their suspension, supplied with ores from Salem. The same company appear to have also established works at Bepur. How long they continued in operation is not known, but they appear to have fallen into the hands of a succession of companies, and the ore is believed to have been derived from the laterite. In 1861 puddling was superseded by the introduction of a Bessemer converter, which does not seem to have been a success, as the works have been closed for some years. In the Kadapah and Karnul districts, Madras, iron ores occur in great abundance, and are treated at a number of native iron-smelting villages situated along the eastern side of the Khundair Valley. Certain tracts in Hyderabad or the Nizam's Territory have long been celebrated for their iron ores, as well as for the good quality of the metal produced from them. In the Orissa Tributary States the manufacture of iron is carried on upon a very small scale, and by an extremely rude process.

In the Birbhum district in Bengal, where attempts, extending from 1777 to 1878, have been unsuccessfully made to introduce the European system of iron mining, the ores are described as being partly earthy and partly magnetic oxides of iron, which occur disseminated in a soapy trappean clay found in beds towards the base of the laterite.

Notwithstanding the abundance of iron ore throughout Sambalpur, Rehrakol is the only locality in which smelting is extensively carried on by the natives. In the Jabalpur district iron ores occur under four distinct conditions, namely, as detrital accumulations, in the Gondwalla sandstones, in sub-metamorphic rocks, and as accumulations in fissures and along lines of fault. In the Narsinghpur district, the ores of Omarpani have long attracted attention

[1] *Geol. Survey of India Records*, xxv. 1894, p. 139.

on account of the excellent quality of the iron manufactured from them. These ores are associated with quartzites and limestones, but their precise mode of occurrence is somewhat obscure. The iron ores of the Chanda district are extraordinarily rich and abundant, and comprehend magnetite, hæmatite, and various lateritic ores.

Among the most important deposits of iron ore in Central India are those of the Gwalior State, which include magnetite and red and brown hæmatites, which were once somewhat extensively worked by the natives, but are now, to a great extent, neglected in consequence of the great distances the ore has to be carried to the fuel. Large deposits of iron ores occur in numerous other localities in Central India, but in one only, namely, at Barwai, does any attempt appear to have been made to introduce European processes of manufacture. The ore is chiefly limonite occurring in irregular masses, but hæmatite is also found in the neighbourhood. In the year 1861 the erection of all the plant necessary for the production of charcoal iron was commenced in this locality by Mr. Mitander, a Swedish metallurgist, but the works were never completed, and, consequently, no iron was produced.

Throughout the Presidency of Bombay iron ores occur in the form of magnetite, hæmatite, and limonite. These ores are all more or less extensively worked in native forges, but we have but little information with regard to their respective modes of occurrence. Although the celebrated Delhi pillar, which is unquestionably the finest known example of Indian metallurgical art, is within the limits of the Punjab, this province is no longer remarkable for its manufacture of iron. The iron ores of the Raniganj field, Bengal, all occur in the ironstone shale which intervenes between the coal-bearing groups of Raniganj and Barakar in the Damuda series.[1] These ironstone shales are traceable at the surface for a distance of several miles, the total thickness of the group being estimated at 1,400 feet. The ore does not occur throughout, but is most abundant towards the top and bottom, where it is found in bands, lenticular masses, or as strings of nodules. It is usually a clay ironstone somewhat altered near the surface, but in some places a regular blackband ironstone has been met with. It is easily obtained at shallow depths, and for a long time no regular mining would be necessary. During the last fifty years propositions have at various times been made to start the manufacture of iron upon a large scale in this locality. The

[1] W. T. Blanford, *Mem. Geol. Surv. Ind.* iii. 1865, p. 191.

matter was not, however, seriously taken up until 1874, when the "Bengal Iron Company" was formed; but in 1879 it ceased operations. The cause of this non-success is attributed, in the first place, to the insufficiency of the original capital, and, in the second, to a heavy and an unexpected charge which was made for the land taken up by the company. The ore, which is of good quality, and contains from 45 to 47 per cent. of metallic iron, was raised and laid down at the furnaces at a cost of about one shilling per ton. From its commencement to the time of its suspension the Bengal Iron Company made 12,700 tons of pig iron, the rate of production being about twenty tons daily. Iron ores occur in the Manbhum, Singbhum, and Harazibagh districts; in the latter the crystalline and metamorphic rocks, said to contain large quantities of magnetite and other ores of iron, were, a few years since, examined by Messrs. Bauerman and Ball, who were of opinion that the accounts previously given with regard to its quantity had been considerably exaggerated. In the sub-division of Palamow, iron ore occurs in well-defined zones of ferruginous slates 200 feet in thickness, of which about 10 per cent. may be regarded as of workable quality.

In the North-West Provinces the existence of rich iron ores in Kumaun was first noticed in the year 1850, and in 1855 Mr. W. J. Henwood was commissioned to visit India and to examine and report upon the iron and copper ores of Kumaun. This report was not favourable to the views previously expressed with regard to iron-smelting upon the plains, and Burrulgaon was consequently selected as the site for an experimental blast furnace. The results obtained were regarded as unsatisfactory, but, nevertheless, with a view of demonstrating the possibility of successfully manufacturing iron upon a large scale in India, the Government in 1857 erected new works at Dechauri, and at the same time a commercial undertaking also commenced operations under the title of "Davies and Co." In 1860 the Government, having become dissatisfied with the results, sold the works, which were bought on behalf of a company which in 1862 became amalgamated with Davies and Co., under the name of the "North Indian Kamaun Iron Works Company, Limited," and in 1864 suspended operations. In 1874 Mr. H. Bauerman visited Kamaun and reported with regard to the advisability of re-establishing the manufacture of iron, but his opinion was unfavourable to the project. This view of the question not having been acceptable to the local authorities, a report was called for from the Geological Survey, and in 1877 the

Government again embarked in the manufacture of iron. In 1879 the works were still in operation, but with unsatisfactory results. The fuel employed was charcoal, and the ores specular and micaceous hæmatite from Ramgarh, occurring in crystalline schist, hæmatites from small veins in quartzite in Kharina, clay ores from Kaladhungi, and siliceous brown hæmatites from Dechauri. These ores, all of which are more or less siliceous, contain from 0·11 to 1·67 per cent. of phosphoric anhydride. Of these localities the first two are in the heart of the mountains at some considerable distance from the furnaces, while the other two are immediately adjacent to them. Although called clay ironstones and siliceous hæmatites, they are actually concretionary limonites of very inferior quality, often containing more sand than iron ore. Throughout India the ores of the crystalline rocks are extraordinarily pure, while those of the sedimentary deposits are lean and contain phosphorus.

In Assam, the principal ores found in the valley of the Brahmaputra are clay ironstones of the Coal-measures, and an impure limonite from the sub-Himalayan strata. Ball states that the only iron ore worked in the native furnaces of the Khasi and Jaintia hills is a titaniferous magnetic oxide, procured by washing ferruginous earths and gravels.

In the Pegu division of Burma, an abundant supply of iron ore is found in the Tertiary rocks of the Eastern Prome District. In Tenasserim, seventeen distinct localities are known in which there are deposits of iron ore, all being situated in the Tertiary hills between Maulmain and Tavoy. Iron is smelted by the natives according to their own methods all over India, but it was only in Bengal that any smelting by European methods was carried on during 1894, at the Barakur Works. These are said [1] to have produced 21,150 tons of pig-iron in that year, but either this return or that of the iron ore raised in Bengal, 24759 tons, may be presumed to be erroneous. The total production of iron ores in India is given as 37,102 tons in 1893 and 38,390 in 1894, but, as the report itself points out, but little dependence can be placed on these figures, as very much ore must be raised and smelted in native forges that never finds its way into the returns The subject of mineral statistics in India is very greatly neglected, and it is impossible to obtain any satisfactory idea of the real amount or value of the mineral production of this vast country.

[1] *Review of Mineral Production in India for* 1894.

The following table shows the production of metalliferous minerals in 1890,[1] and the provinces whence they come:—

	Production.	
Bengal.		
Copper ore	4,415 tons	15,600
Gold	...	6
Iron ore	17,853	2,086
Ochre	147	67
Burma.		
Gold	32 ounces	120
Lead ore	14 tons	92
Tin ore	37 ,,	2,880
Central Provinces.		
Iron ore	5,664 tons	863
Madras.		
Gold	1,694 ounces	6,435
Iron ore	238 tons	500
Ochre	85 ,,	31
N. W. Provinces and Oudh.		
Gold	77 ounces	276
Iron ore	18 tons	439 (*sic*)
Ochre	29 ,,	4
Punjab.		
Antimony ore	72 tons	275
Gold	447 ounces	1,507
Iron ore	23 tons	4
Ochre	82 ,,	47
Native States.		
Gold	107,079 ounces	385,216
Bismuth and Cobalt ores	3 cwt.	7
Chrome ores	16 ,,	8
Copper ores	1 ,,	2
Iron ore	4,499 ,,	9,121
Ochre	226 ,,	68

[1] "Return of Minerals and Gems produced in each British Province and Native State during 1890," quoted in the *First Annual General Report upon the Mineral Industry of Great Britain for* 1894, p. 71.

The following table of returns for 1894 is said in the report[1] not to be anything more than a convenient tabulation of such particulars as are annually procurable :—

Gold—Mysore	210,082 ounces	211,770 ounces	£717,010
,, River sand washing	1,688 ,,		
Iron ores—British India	33,959 tons	38,390 tons	12,520
,, Native States	4,431 ,,		
Antimony (? fused)	—	411	?
Copper	—	?	?
Manganese ore—Madras	—	11,400	?
Tin—Mergui	—	98	4,480

THE MALAY PENINSULA.

The narrow strip of land which forms the Malay Peninsula has long been known for its mineral wealth. Travellers have at all times celebrated the metallic riches of the Malay archipelago, and ancient historians speak of an active commerce existing long before the Christian era between India and the western countries of Arabia, Egypt, Greece, &c. The Malay Peninsula was not less celebrated for its richness in minerals, as it figures on the maps of Strabo and Ptolemy under the significant name of the Golden Chersonese. The settlement of Malaka seems to have been an important commercial centre as far back as the sixteenth century, and was probably the first point of the peninsula touched by European traders; the chief products obtained were tin and gold, but it seems probable that the latter was largely collected from the neighbouring islands of the archipelago. Tin appears to have been produced for a long time in the State of Perak, though it is noteworthy that the name means not tin but silver. Godinho de Eredia, at the beginning of the seventeenth century, states that the country of Viontana, now called Sungei Ujong, produced gold, silver, mercury, tin, and large quantities of iron.

The celebrated French traveller, Tavernier (1677), states that the money in Queda and Perak was made of tin ; this coin weighed $1\frac{1}{2}$ oz. and passed for two "sols." The value of tin in Perak must consequently have been about 2,200 francs or £88 per tonne. Tin money, cast in the form of a hollow truncated square pyramid, was, till after the establishment of a British protectorate in Pahang, current in that State, although Pahang is by no means one of the States richest in tin. In Reman, Legeh, Patani, and Teluban, coins

[1] *Review of Mineral Production in India for* 1894.

are still current cast in iron moulds from an alloy of lead and tin, these last-named States being under Siamese jurisdiction.

The Malay Peninsula forms a narrow strip whose length from the isthmus of Kra in the north to the island of Singapore at its southernmost extremity is some 600 miles; its greatest width is only about 180 miles and its average width may be taken as little over 120 miles. There are three British colonies which together form the Crown Colony of the Straits Settlements, namely Singapore in the extreme south, and Malaka and Penang on the west coast. The southern two-thirds of the Peninsula is under British influence, consisting of the independent Native State of Johor in the south, and several protected Native States, namely the State of Pahang on the east coast, the States of Sungei Ujong, Selangor and Perak on the west coast, and the inland States of Negri Sembilan and Jelebu, the latter partly incorporated with Sungei Ujong. The upper portion of the Peninsula is under Siamese protection, the various rajahs paying tribute to the King of Siam. The most important are Kedah on the west coast, Tringganu and Kelantan on the east, and on the north, the ancient State of Patani, now split into several smaller ones, such as Reman Legeh, Teluban, Jalor, Patani, &c., and Singgora. There is a main mountain chain running parallel to the west coast and comparatively close to it, whilst a huge transverse chain running from it to the east forms a central mountain mass that separates the basin of the Pahang river and its tributaries from the rivers Patani, Teluban and Kelantan. This central mountain mass is still unknown to Europeans. All the mountain axes are everywhere, in the main, granitic; against the flanks of the granite lie highly metamorphic slates and schists, often micaceous and talcose and at times graphitic, with occasional sandstones passing more or less into quartzites. Both granite and stratified rocks are in places overlain quite irregularly and apparently unconformably by white crystalline saccharoidal limestones; these are too thoroughly metamorphosed to show any organic remains, but their mode of occurrence suggests ancient coral-reefs. Eruptive rocks, chiefly diorite and felsite, in places traverse both the granite and the schists, but play quite a subordinate part in determining the physiography of the country. A great deal of laterite occurs in various places, which may possibly be the result of extreme weathering *in situ* of some of the older formations; the connection of this laterite with the older rocks has not been traced. In the extreme south are softer red-coloured sandstones and shales. Finally the east and north-east portion of the Peninsula consists very largely of extensive sandy plains, possibly of very recent formation. On the north coast the area of the land is still being extended by the accumulation of extensive sandbanks.

TIN.—The most important mineral product is tin ore; almost the whole of it is obtained from alluvial deposits of the nature described on page 34. These deposits are found in practically every valley that descends from the main axial range of the Peninsula, and particularly on the western coast; as this range only becomes well defined to the north of Malaka, this colony has practically no tin deposits; it may be noted that none of the actual British colonies yield any tin to speak of. What is known as "Straits Tin" in England and "Malacca Tin" in America, is really the tin from the various States of the Malay Peninsula, which is collected and shipped in the Straits Settlements of Singapore and Penang. The States of Perak and Selangor together produce about nine-tenths of the tin of the Peninsula. It is all worked by sluicing by Chinese miners, who either smelt it themselves in native charcoal furnaces or sell it to a European company for smelting in Singapore. The ore thus produced averages about 68·3 per cent. of metallic tin.

The following table [1] shows the proportions in which the various Native States under British protection have contributed to the total of production in recent years, all the production being calculated as metallic tin:—

	State.	1892. Tons.	1893. Tons.	1894. Tons.
West Coast	Perak	15,175	17,480	22,190
	Selangor	10,850	15,050	20,440
	Sungei Ujong	2,635 }	2,960	about 2,900
Inland	Jelebu	1,620 }		
	Negri Sembilan	About 75 tons per annum.		
East Coast	Pahang	250	270	435
	Total	30,605	35,835	46,040

The source whence the tinstone was originally derived has long been doubtful; the Chinese have always been contented to wash the pay gravel, working merely down to the bedrock, which is generally an impure kaolin formed by the decomposition *in situ* of granite, without examining this bedrock any further.

[1] Compiled from the *Official Papers relating to the Protected Malay States.*

Recently a European company has been working some deep-lying tin gravels at Kuchai, Selangor, which had proved too deep for the Chinese open-cast method, by mining on the pillar and stall system, and in so doing they found leaders and veinlets of tinstone in the kaolin,[1] and these apparently continued down into a rock composed of quartz and felspar. Somewhat similar occurrences have also been noted at Sungei Rin in Jelebu, and small veins of tinstone that never continued very far have been opened up in Perak. It would therefore appear that these tin alluvials are the result of extensive disintegration of stanniferous greisen or granite, showing in places small veins of cassiterite, exactly analogous to the stockworks of Saxony and Bohemia. It is obvious that, in a country still so imperfectly known, covered with dense jungle, where great heat and heavy rainfall contribute to disintegrate the rocks to very great depths, and which has never been systematically explored, a greisen containing only a small percentage of tin would readily enough escape discovery; at the same time, it may also be that, as at Zinnwald, it was only the outer portions of the granitic masses that carried the tin, and that practically the whole of these have suffered disintegration, so that only small remnants may still be left to be discovered.

The tin sands are very variable in both their depth and their richness. As an average the depth of overburden may be estimated at 15 to 20 feet, and the thickness of the tin-bearing sands (the *karang* of the Chinese miners) 4 to 5 feet. The extremes are from 5 to 80 feet of overburden and 1 to 15 feet of pay gravel. An exceptional case was met with at Sorakai, Kinta, in Perak, when a depth of 20 feet of overburden under which were over 80 feet of tin sands was excavated by some Chinese miners. The average richness of the pay gravel proper is probably about 1 per cent. of black tin, though exceptionally as much as 20 per cent. has been met with in abnormally rich spots like some at Saiak, Kinta (Perak).

As already stated, most of the tin is produced from the western side of the main range, not only because the tin fields on that side are richer and possibly more extensive, but also because they are far more accessible and transport to the sea is less costly. There are, however, rich fields known on the western side, as at Hulu Pahang, Tras, Bentong, and Jelebu. Some of the tin raised in

[1] *Reports on the Protected Malay States for* 1894, p. 35.

the former places is shipped *viâ* Selangor and appears in the Selangor returns. Johore is very poor in tin; some small fields have been opened there, but being poorer than the others, are not worked. Of the Siamese Native States, Kedah is known to be rich in tin, and especially so is the small island known as Junk Ceylan.

There are no statistics as to the production of these States, but most of the tin produced by them is brought to Penang to be shipped. The amount so imported is probably three to four thousand tons a year. Some is, no doubt, sent direct to India and Siam proper. Similar alluvial deposits are known to exist in Tringganu and on the rivers Teluban and Patani, where some very rich tin ore is raised. A very pure white cassiterite, said to occur in decomposed (granitic) rock, is also produced in the same region. Further north again, within five miles of the northern coast, alluvial tin is worked to a small extent on the head waters of a stream known as the Klabar, an affluent of the Teluban, which takes its rise in a small isolated range of granitic hills. The tin belt evidently extends further north still, because deposits of alluvial tin have been worked to a small extent in Chantabun in Siam, as well as in Mergui in Burma.

The amount of tin obtained by lode mining is comparatively quite insignificant; it is nevertheless interesting to note that tin lodes exist. The most important are those worked by the Pahang Corporation in the district of Kuantan near the eastern coast of the Peninsula. Little is known of the geology of the district; the country rock of the lodes consists of blackish-coloured chloritic schists overlying granite, with occasional dykes of porphyritic granite traversing the strata.

The tin lodes have not yet been followed down into the granite, the deepest shaft having been only 250 feet deep in 1895. The lodes are narrow, averaging from 2 to 3 feet in thickness, and the veinstuff consists chiefly of quartz with chlorite and calcspar, the principal metalliferous minerals being cassiterite, iron and arsenical pyrites. The lodes do not as a rule show well-marked walls, and have probably been formed by metasomatic action on the schists, the mineralising solution having made its way through narrow fissures. There are several independent lodes known here; their general course is east and west and they are nearly vertical. The tin ore runs in pay shoots with barren or nearly barren intervals. The ore as stoped is very rich, having averaged about 4 per cent. (in some months as high as 8·6 per cent.) of black tin, the latter containing 70 per cent. of metal.

The following have been the returns made by the Company [1] since crushing commenced :—

Period.	Stone crushed. Tons.	Black tin produced. Tons.	Percentage of black tin.
Up to Sept. 30th, 1890	?	68	?
Oct. 1st, 1890, to April 30th, 1891	3,770	84½	2·2
May 1st, 1891, to June 30th, 1892	5,243	259½	4·9
July 1st, 1892, to June 30th, 1893 [2]	5,522	197½	3·6
July 1st, 1893, to June 30th, 1894	5,272	321½	6·1
July 1st, 1894, to June 30th, 1895 [3]	7,360	506	6·9
July 1st, 1895, to Mar. 31st, 1896	13,811	672	4·9

Lode tin is said to be worked also by an English company mining at Bundi on the River Cheroe in the State of Tringganu; the deposit is described [4] as a band of slate about 30 feet wide, resting against granite, with a north and south strike. This slate is said to be stanniferous throughout, and to carry some five per cent. of metal. Operations were commenced in July, 1894, and in the first year 40 tons of black tin were shipped. It is not known whether this is a true lode, or whether it is a cement deposit.

Stanniferous Cements.—Curious deposits of what look like siliceous bog iron ores carrying tinstone are met with in several places on either flank of the great east and west hill range, among them being Bukit Ebu, near Kernai, on the southern side, and Dreda and Goa Tumbus in Jalor on the northern side. The deposit at the first-named place trends north] and south, and is about 60 feet wide. At Dreda there are a number of smaller deposits found cropping and lying at steep angles on the hill sides, usually on granite. These deposits have been formed apparently by the disintegration of granite containing tin in the neighbourhood of large deposits (probably fissure veins) of pyrites, the iron from which cemented together the grains of tinstone and grains of quartzose sand into a hard compact mass; it is so hard that the Chinese who work it have to break it out, stamp it in rude foot stamps,[5] and wash the crushed stone to separate out the tinstone. The richness seems to be, as would naturally be expected, very variable. Some of the stuff seems to carry 30 per cent. of black tin, whilst the Chinese reject all that carries only 1 per cent. or less.

[1] Directors' Annual Reports to the Shareholders of the Pahang Corporation, Limited, and private communication from the secretary.

[2] In this year a certain amount of poor ore had to be crushed, as the shaft had not been got down deep enough to allow stoping to be carried on to any extent.

[3] A new mill at Jeram Batang was started on the 1st of May in this year.

[4] H. Louis, "Straits Tin," *The Western Daily Mercury*, April 18, 1895.

[5] *Cf.* H. Louis, "A Chinese System of Gold Milling," *Trans. Amer. Inst. Min. Eng*, xx. 1891, p. 324.

At Goa Tumbus, a very curious deposit of this kind is worked by the Chinese, which contains small particles of various oxidised lead ores (chiefly anglesite, cerussite, pyromorphite and mimetite) in addition to the tinstone, as the result of the simultaneous disintegration of stanniferous granite and of small deposits of galena which exist in this locality. The mixture of lead and tin ores thus obtained is smelted by the Chinese in their customary small charcoal furnaces, and an alloy of the two metals is thus obtained.[1]

GOLD.—A well-marked auriferous belt appears to traverse the Peninsula in about a N.N.E. direction, and gold has been mined at many points along it. The most southerly point at which it is known is on the north flanks of Gunong Ledang (spoken of by Europeans as Mount Ophir) on the boundary between Malaka and Johore. A considerable area of shallow alluvial ground has been washed over, but it is all exhausted now, and there is no record even of the period when it was worked. A few irregular veinlets of quartz in highly decomposed shales, which yield a little gold on assay, are known to exist. Alluvial gold has also been worked in one or two other spots in this district.

A good deal of work was done some years ago on a lode at Chendras, near Gemencheh in Negri Sembilan, which was mined for some time by a Singapore company. Although a fair amount of gold was obtained, it had ultimately to suspend operations. The Malays in this district still do a little alluvial mining, principally by washing the sands of some of the streams in the Johol district, but the amount of gold so obtained is very small, and is not known with even an approach to accuracy. The most important gold mines are in the State of Pahang. At the Raub Mines a series of thin irregular branching veins of quartz running through a belt of graphitic schists are being worked; the strata strike about N. 25° W., S. 25° E., dipping 85° to the eastward, having apparently been tilted by the granitic axis of the mountain range, which is not very far from, and to the west of, this spot. The general direction of the veinlets of quartz is N. 60° E., S. 60° W.; these veinlets are in places very rich, and carry much free gold, together with stibnite and iron pyrites. In addition to these there is a stronger reef from one to eight feet in width, running about N.N.W.—S.S.E., and nearly vertical, which has been traced for some four miles. The greatest depth reached was

[1] H. Louis, "On the River Teluban," *The Geographical Journal*, 1894, September, p. 235.

234 feet in 1896. After working under great difficulties for some years, this mine produced 4,886 ounces of gold in 1893, the yield being at the rate of 1 oz. 2 dwts. of gold per ton; in 1894 the output was about 6,000 ounces, and 6,173 ounces in 1895 from 12,241 tons of stone crushed, being at the rate of 10 dwts. $2\frac{1}{2}$ gr. per ton. Since the commencement of operations there have been crushed 30,253 tons, yielding 20,356 ounces.[1]

At the Jalis Mine, belonging to the Penjom Company, a great deal of work has been done upon a rather broken lode of quartz running in soft shales, approximately north and south, and nearly vertical. The gold belt is well developed in this district, being known for about a mile in width and ten miles in length. Numerous other mines are being opened up in this belt, but Jalis takes the lead so far, having been proved to a depth of 168 feet in 1893,[2] and having been a steady gold producer for some years, as shown in the following table:—

Year.	Quartz Crushed. Tons.	Gold got. Ounces.
1890	1,000	200
1891	2,700	1,025
1892	3,000	2,500
1893	4,800	5,380
1894	?	6,000 to 7,000
1895	?	8,000 to 9,000 (?)

Two other companies are at work in this same district, at Cherubang and Silinsing respectively; the last named got 527 ounces in 1893 from 1,100 tons of stone,[3] and is continuing to work steadily. The gold belt has not been traced much further north in Pahang, and seems to be cut off by the great east and west granitic range already spoken of. Immediately to the north of this range, and close in some places to the granite, the gold belt reappears and extends farther north for another thirty miles or so. The district of Pulai in Kelantan is said by the Malays to be exceedingly rich in alluvial gold. Other points, such as Blimbing and Tadoh, have also yielded a good deal of alluvial gold, most of which is now exhausted. The valley of the Teluban is the richest in gold of any of the northern rivers, or, indeed, of the entire Peninsula.

[1] *Report of the Manager for the year ending February*, 1896.
[2] *Reports on the Protected Native States for* 1893, p. 97.
[3] *Reports on the Protected Native States for* 1893, p. 100.

It would seem that large Chinese colonies, some consisting of as many as a thousand men, made their way into this valley and commenced working the alluvial, which is found in shallow placers on either side of the Teluban River and some of its affluents, as well as in the beds of the streams, about a century and a half ago. Now—in 1895—the alluvial is practically exhausted, there being probably not over 100 men washing for gold in the entire length of the river; a man seems on the average to get about 10 grains of gold as the result of a day's river washing, so that the total amount of alluvial gold got is but small. The Chinese are said to have turned their attention to the reef gold some 60 years ago, and worked it in a number of places, breaking out the quartz and crushing it under tilt hammers worked by foot or by water power; the crushed stone is then washed in wooden dishes and the gold thus collected.[1] The country rock throughout this gold district consists of brown, red and yellow shales and schists, sometimes micaceous, talcose, or chloritic, passing at times into black fissile slates, at times pyritous, through which run numerous small, narrow, irregular veins of gold quartz, which join each other so as to form a system of reticulated veins, which are rarely a foot, and mostly from three to nine inches, in thickness. These veins are approximately parallel to the general strike of the strata, their strike being N.N.E.—S.S.W., and their dip variable, but mostly to the west. Some of these veinlets are very rich, assaying as much as 11 ounces to the ton; in some of them, highly auriferous iron pyrites, which the Chinese are unable to treat, is also found. The Chinese generally get from one to four ounces of gold to the ton of stone by their method of working.

The State in which these mines are situated, known as Tomoh, is in reality a province of Legeh, and is subject to Siam. It is administered by a Chinaman, who controls the gold mines, and pays an annual tax of about £150 in gold to Siam, besides tribute in kind collected by the Siamese viceroy at Singgora. Accurate statistics are not available, but the annual output may be estimated at fully 4,000 ounces, quite three-fourths of which is derived from reef mining. In the State of Legeh, on the headwaters of the Tanjong Mas River (Malay: *tanjong*, bend of river; *mas*, gold), some alluvial has also been worked. There are also some parties of Chinamen working auriferous laterite on a small scale; some of it is hard enough to require crushing, some can be sluiced.

[1] H. Louis, "A Chinese System of Gold Milling," *Trans. Amer. Inst. Min. Eng.* xx. 1891, p. 324.

The total gold output of the Malay Peninsula can only be very roughly estimated; in 1894 it was probably about 20,000 to 25,000 ounces, of which Pahang contributed 15,000 to 16,000 ounces. It is not likely that more than 1,000 ounces of this total would be alluvial gold.

Lead, &c.—Lead ores are known to exist in several places in the Malay Peninsula. The best known locality is at Goa Tumbus, near the Patani River, where a Singapore company commenced operations some years ago, but had to abandon the enterprise after erecting costly smelting and desilverising plant. The granite in this district is overlain in many places by masses of limestone, and at the contact of these rocks, or sometimes in the limestone itself, masses or pockets of galena occur, generally of somewhat limited extent.

The galena is argentiferous, its silver contents having been found to vary between 20 and 60 ounces to the ton. There are also in this district other deposits that seem to be fissure veins carrying iron and arsenical pyrites, galena, zinc blende and some copper ores, but these have never been worked.

In Tringganu a somewhat similar deposit of galena and zinc blende with arsenical pyrites is also known to exist.

In Pahang, within the concession of the Pahang Corporation, Limited, a lode about five feet wide is known, which, in the upper part, carried galena assaying 30 ounces of silver, but on sinking upon it, the galena was replaced by zinc blende.

Numerous other minerals, including ores of copper and of cobalt have been met with in this concession, but none hitherto of workable value.

Stibnite occurs in the gold quartz veins, and deposits of it are known in other localities, but have never been worked.

In addition to the gold output already given, the only metal of economic importance is tin. Accurate statistics are not available; the Siamese Malayan Provinces export some tin direct to Siam and possibly China, while a good deal is consumed in the country, of none of which any record at all is obtainable. The Siamese Malayan States on the west coast export a certain amount to Penang whence it is re-exported, and therefore figures as a portion of the total export. The quantity thus imported into Penang was 2,500 tons in 1892, and 3,500 tons in 1893. The following table shows the export of tin from the Straits Settlements to Europe and America; in addition to these amounts about 4,000 tons are exported annually to China and India, the latter country taking 2,200 tons in 1893 :—

TABLE SHOWING THE AMOUNT OF TIN EXPORTED FROM THE STRAITS SETTLEMENTS TO EUROPE AND AMERICA SINCE 1880.

Year.	Quantity. Tons.
1880	11,735
1881	11,400
1882	11,705
1883	16,958
1884	17,548
1885	17,320
1886	19,674
1887	23,977
1888	23,855
1889	26,112
1890	27,390
1891	31,567
1892	34,273
1893	39,944
1894	46,284
1895	47,685

SIAM.

Nothing practically is known of the geology of this vast country. The tin belt that extends throughout the Malay Peninsula seems to continue into Siam. Deposits of alluvial tin are worked on some of the islands off the Isthmus of Kra on the western side as already mentioned, and alluvial tin has also been found, though worked but to a very small extent, if at all, in the district of Chantabun, more famous for its sapphire and ruby mines. Mines of antimony are also known to the natives. Of the metallic minerals gold is the most important. An English Company, "The Goldfields of Siam, Limited," worked alluvial and reef gold at Pechiburi on the eastern side of the Isthmus, but the operations proved unprofitable, in spite of the undoubted existence of gold in fair quantities.

A great portion of the extensive flat country on either side of the Petriou River is auriferous; the natives have worked in a few localities, mostly in a radius of ten miles or so round the village of

Moung Kabin. A ferruginous "cement," possibly ferruginous laterite, yields a little gold in several places, and there are several spots at the foot of the Kao Kampeng range that show gold bearing gravels which the Siamese have worked. These deposits are everywhere very poor, and the quantity is limited; the natives only work them at the close of the rainy season, when water is plentiful, and when they have apparently no other occupation. At one spot close to Kabin, where a good deal of gold had been got in an alluvial flat, mining operations were commenced on what seems to be a reef. This had been worked in the form of an open-cast some 200 feet long, 30 to 40 feet wide, and 120 feet deep, the longer axis running about east and west. The country rock consists of shales, but basaltic rocks also exist in the district; the gangue is a curious mixture of quartz and calcite with grossularia and red garnet, carrying free gold. An English company has recently been formed to work this place, but no results have been obtained so far. It had originally been opened up on behalf of the King of Siam, one of the high officials of the kingdom being in charge of the operations. After a good deal of money had been spent without result, the king ordered the mines to be closed down and the manager to be decapitated. A French company has commenced operations nearer the Kao Kampeng Mountains at a place called Wattana, where rich reefs are said to exist. Further in the interior, gold is worked by the natives (Siamese and Laotians) in a good many places, but nothing definite is known about them, nor are any statistics respecting the output available.

Malay Archipelago.

The most valuable mineral product of the islands that compose the Malay Archipelago is tin, which is produced chiefly in the Dutch East Indian possessions, the two small islands of Banca and Billiton off the south-east coast of Sumatra being by far the most important. Geologically speaking, these deposits are simply a continuation of those of the Malay Peninsula, being precisely identical in character; the axis of their hill ranges consists of granite in which dykes of porphyry and felsite occur, and against these masses of granite rest highly inclined slates and sandstones of probably Silurian age. According to Van Diest, quoted by C. M. Rolker,[1] the average ratio of pay gravel to

[1] "The Alluvial Tin Deposits of Siak, Sumatra, *Trans. Amer. Inst. Min. Eng.* xx. 1891, p. 50.

barren overburden in Banca is 3 ft. to 33 ft., and the richness varies from 2·95 to 4·46 lbs. of metallic tin for each cubic metre of excavation. Tin has been worked in Banca since 1710, but its energetic exploitation dates from the occupation of this island by the Dutch in 1821. Work was not commenced in Billiton till 30 years later. The mining is practically all done by Chinese, who mine and smelt the tin and ship it to Batavia, in the island of Java, whence it is exported to Europe. The Dutch government levy a tax on all the tin produced; it also controls a large proportion of the Banca tin mines, those on Billiton being mostly under the Billiton Maatschaapij. Part of this tin goes to China and India, but that destined for Europe is sold by auction at Rotterdam and Amsterdam. The following tables show the proportions of tin furnished by the various districts in these two islands and their total production in recent years :—[1]

PRODUCTION OF METALLIC TIN IN THE VARIOUS DISTRICTS OF BANCA IN THE YEAR 1892-3.

District.	Production. Tons.
Muntok	379
Jebus	867
Blinju	1,339
Sungei Liah	1,408
Merawang	788
Pangkal Pinang	1,105
Sungei Slan	731
Koba	222
Toboali	407
Total	7,246

The number of miners employed was about 9,860.

PRODUCTION IN THE VARIOUS DISTRICTS OF BILLITON IN THE YEAR 1892-93.

District.	Number of Mines.	Number of Miners.	Black tin produced.	Metallic tin produced.
			Tons.	Tons.
Tanjong Pandang	18	780	434	288
Manggar	22	2,970	2,786	1,857
Linggang	18	2,350	2,131	1,418
Buding	20	1,470	1,161	772
Dindang	13	560	500	330
Totals	91	8,130	7,012	4,665

There were also some 4 tons of wolfram produced in 1892.

[1] *Jaarboek van het Mijnwezen in Nederlandsch Oost-indie*, 1894

Total Production of Metallic Tin in Banca and Billiton for the Years 1887 to 1893.

Years.	Banca.	Billiton.
	Tons	Tons.
1887–88	5,022	4,633
1888–89	3,926	4,714
1889–90	5,339	5,731
1890–91	6,380	5,743
1891–92	5,573	6,324
1892–93	7,246	7,012

In the small island of Singkep, close to Billiton, similar stanniferous alluvial deposits occur in some of the valleys, notably in those of Daba and Jangkang; these are worked by a Dutch company, the Sinkep Tinmaatschapij, who employ about 450 miners; their production in tons of metallic tin has been as follows :—[1]

1889–90	1·7	tons
1890–91	25	,,
1891–92	70	,,
1892–93	176	,,

In the island of Sumatra itself, alluvial tin deposits also occur, though they are unimportant. A company was formed to work some deposits at Siak in the valleys of the rivers Lan and Rambei; according to C. M. Rolker,[2] the bed rock consists of sandstones and quartzite; there are also exposures of granite consisting of quartz, albite, white muscovite, and tourmaline, which rock possibly underlies the sandstones. The gravel is 0·54 feet thick in one spot that was tested, and the overburden 5·47 feet; its richness is only 2·7 lbs. of black tin carrying 70 to 72 per cent. of metal to the ton. This works out to 0·348 lbs. of metal to the cubic metre of excavation, or about one-tenth of the produce obtained in Banca. According to official statistics, Siak produced half a ton of black tin in 1891, and has since then been closed down as being apparently too poor to pay.

Borneo.—The interior of this enormous island is still practically unknown, but it evidently contains much mineral wealth; gold placers and gravels containing pebbles of waterworn cinnabar

[1] *Jaarboek van het Mijnwezen in Nederlandsch Oost-indie*, 1894.

[2] "The Alluvial Tin Deposits of Siak, Sumatra," *Trans. Amer. Inst. Min. Eng.* xx. 1891, p. 50.

are known to exist, but nothing definite is known about them. Among the mineral products that have been worked under European supervision are gold, platinum, silver, mercury and antimony. Gold occurs chiefly in Montrado and Sambas, both in alluvial deposits and in quartz reefs; the latter have been several times attacked by European companies, but the results were not very encouraging. A Dutch company is said to have got in 1891 gold to the value of £1,650.

The production of Montrado is considerably more important; between the years 1880 and 1887, the total production of Montrado and Sambas together amounted to about 150 kilogr. yearly, out of which Sambas only contributed some 2 or 3 kilogr. on the average. Alluvial gold is also obtained in the Landak valley. The following were the amounts of gold obtained by alluvial washers in 1892 in Western Borneo:—

Division.	
Mampama	1·5 kilogr.
Landak	14·6 ,,
Montrado	71·9 ,,
Sambas	6·6 ,,

Borneo also produces a certain amount of platinum, respecting which no statistics are available; it occurs at the south-eastern extremity of the island, where the rocks chiefly consist of serpentine, diorite, and gabbro, covered by a deposit of clay fifteen feet in thickness, under which is an auriferous bed containing magnetic iron sand, platinum, and iridosmine.

Antimony was discovered in Borneo in 1825. The chief mine is at Bidi in Sarawak, and in 1880 antimony to the value of \$72,516 was exported. During the same year the export of quicksilver amounted to \$66,300.

The value of the mineral exports from Sarawak in 1884,[1] was as follows:—

Gold	\$9,574
Mercury	\$3,550
Antimony	\$57,853

In 1882 Sarawak exported 1,387 tons of silver ore, 52 tons in 1883, and none since then.

A very curious deposit is described by N. W. Easton[2] as occurring

[1] *Jaarboek van het Mijnwezen in Nederlandsch Oost-indie*, 1886, p. 130.

[2] *Het Verkomen van Bismuth op het Schiereiland Samosir* (*Tobameer*), *Jaarboek*, &c., 1894, p. 84

in Samosir, where he has found a small patch of river sand containing alluvial native bismuth; the deposit rests on a bed of tufaceous sandstone, and the metal occurs in small rounded masses covered with clay, having possibly been derived from small pockets in the sandstone, although careful examination could discover no trace of bismuth in the latter. The only accompanying mineral was specular iron ore. The metal was usually found in depressions in the sandstone. It has not been found in commercial quantity, only half a kilogr. having been collected. The mode of occurrence is decidedly unusual.

No statistics of the annual mineral output of Borneo are obtainable.

THE PHILIPPINE ISLANDS.

This group of islands, extending from about 5° to 20° N. lat., and 118° to 128° E. long., has been but most imperfectly explored, but is, nevertheless, known to contain considerable mineral wealth. The chief islands of the group are Luzon and Mindanao, Cebu, Negros, and a number of smaller ones. Practically all that is known concerning their mineral and geological occurrences is what can be gathered from the reports of the various Spanish inspectors of mines who have been stationed in the colony.[1] Hitherto the chief interest has centred in the coal deposits, which are known in the south of Luzon, in Cebu, Negros, Mindoro, and others of the islands.

Gold.—Alluvial deposits, more or less rich in gold, seem to be widely scattered all over these islands, and to have been worked in an intermittent desultory fashion for very long periods. The first authentic record seems to be in 1643, when certain archives relate to the collection of a tax known as "the fifth of the gold" for his Majesty the King, in Luzon. In 1701, and again in 1755, Spanish adventurers established gold-washing operations in Mambulao, in the district of Camarines Norte, and it is said that one of these at any rate made great sums of money as the result of his mining ventures. In 1850, two Spanish companies, "El Ancla de Oro" and "La Explotadora," commenced operations in the same district, the first one close to Mambulao, and the second on the boundary

[1] The following information has been chiefly derived from such official sources, and mainly from a report by Señor Don Jose Centeno, formerly Director-General of Mines at Manila, kindly communicated by Mr. Frank Karuth.

between the Labo and the Malaguit, near Paracale. A great deal of work seems to have been done, and, though nothing is known of the results obtained, both these companies had suspended operations by the end of 1859. The natives, however, still carry on a certain amount of desultory work in this district, chiefly washing in the river beds; it is estimated that the amount of gold so obtained is about 30 ounces per month on the average. Numerous other localities might be named in the island of Luzon, chiefly in the province of Nueva Ecija, where similarly rudimentary gold-washing operations are carried on intermittently by the natives. At Paracale and Mambulao gold is found as more or less heavy nuggets in pockets, generally associated with iron pyrites and sometimes copper pyrites, zinc blende, peacock ore, galena, and occasionally chromate of lead in fine crystals. In Labo veins are known consisting of a clayey matrix, in which occur gold, galena, zinc blende, iron pyrites, and sometimes, though rarely, native copper. These veins mostly run N. and S., except at Cumihan and Mount Lugas, where their course is N.W. and S.E.; they are almost vertical, and generally from 1 to 5 inches in width, though at times much wider. The country rock, as far as known, seems to consist of micaceous and talcose schist, together with granite, porphyry, eurite and dolerite.

In Mindanao, the districts of Misamis and Surigao, in the north-eastern part of the island, are known to be rich in gold. In the first-named district the rivers Cagayan and Iligan seem to be noted for their richness in gold. The alluvial deposits appear to be the products of the degradation of highly decomposed eruptive rocks; the gold occurs in the form of the finest dust up to nuggets of 5 ounces in weight. Veins of auriferous quartz in talcose schist are known to occur near Cagayan. The annual product of this district is estimated at 2,000 ounces. Surigao is supposed to be even richer than the last-named district, the chief centres of gold washing being in the mountains of Canimon, Binutong and Canmahat. The formation is said to be talcose schist with some serpentine, and in the former veinlets of quartz and calcspar carrying gold, from ½ inch to 3 inches wide, are known. In the calcareous veins the gold is accompanied by iron and copper pyrites, galena and zinc blende. It is noticed that the richer veins all run E.—W., veins in other directions being poorer or sterile, but no serious work has yet been done. There is no reliable information respecting the gold production of this district. An English company has recently commenced operations on what are described as some extremely promising gold quartz reefs in Mindanao, and returns are expected before very long.

Gold is also known to occur on many of the other islands of the group, such as Cebu, Mindoro, Panay, Sibuyan, Rapurapu, and several others.

Other Metals.—Of these the most important is copper, the existence of which in the Philippine Islands has long been known; it has been worked and smelted by the natives, and curious horse-shoe shaped pieces, weighing about ½ lb., were at one time current in Luzon as money. The most important mines are those of Mancayan, in the district of Lepanto, in the north of Luzon. Here there are very extensive veins running in a body of quartz of very varying texture, from 80 to 100 metres thick, and overlain by argillaceous porphyry. This mass of quartz is frequently crossed by veins of decomposed felspar, and contains numerous pockets of copper ore, whose general direction is W.N.W. to E.S.E., coinciding with that of the known lodes. The total amount of information available is very meagre, little beyond the main fact that copper exists in large quantities being known. Mercury is said to exist in Mindanao, but nothing definite is known about it; galena is also reported in the island of Cebu. No mineral statistics are obtainable.

JAPAN.

The earliest accounts we have of Japan [1] represent that country as possessing great metallic wealth. Marco Polo tells remarkable stories about the gold in "Zipangu." Kæmpfer, in 1727, speaks of the mineral wealth of Japan, and especially of the abundance of gold. While the Portuguese and Dutch had trading stations in the country, it furnished tangible evidence of the truth of these early reports. Between 1550 and 1639 the Portuguese merchants sent home nearly $300,000,000 worth of bullion, chiefly gold. After the Portuguese the Dutch continued this trade, and between 1649 and 1671 sent home over $200,000,000 in bullion, of which, however, nearly two-thirds was silver. In 1671 the Japanese Government issued an edict stopping this commerce. Between 1609 and 1858, about 280,000 tons of copper were exported by the Dutch, and 250,000 tons by Chinese merchants.

[1] H. S. Munroe, "The Mineral Wealth of Japan," *Trans. Amer. Inst. Min. Eng.* v. 1877, p. 236.

Kæmpfer, in 1727, enumerates iron and tin, in addition to gold, silver, and copper, as products of Japan.

Of all the metalliferous minerals, the ores of iron are the most abundant, and nearly all the different varieties are represented in Japan, but magnetite and magnetic iron sand are probably the most important. In 1874 more than 400 washings for iron sand were in active operation.

Copper is comparatively plentiful, but although it has been mined, to some extent, for nearly twelve centuries, the active working of the mines dates no farther back than about 300 years. The average annual production during the past 250 years has been about 2,800 tons; in 1830 it was 4,000 tons, and in 1874 3,360 tons. This represents the united product of about 200 different mines, but, among these, only four furnish about one-half the total amount. Copper ores occur in veins which are sometimes true fissures, but more frequently they are of limited extent, and are apparently irregular deposits. In both cases there is usually a certain parallelism between the different veins in the same region. In recent years, the production has risen rapidly[1] from 3,900 tonnes in 1879 to 11,000 in 1887, 15,000 in 1890, and 18,250 in 1892. The most important mines are in the north of Nippon, in the province of Rikuchu, and in the island of Shikoku. The principal mine is that of Ashio, about 100 miles north of Tokio, which has produced in recent years about 8,000 tons of copper annually.

The deposits of lead ore in Japan are neither numerous nor particularly valuable. Galena occurs in veins associated with ores of copper and silver; in 1874 thirty-five mines produced 207 tons of lead, more than half of which was the yield of a single mine. Of the remaining mines probably two-thirds yielded less than a ton each.

Tin ore occurs only in veins, although it has been stated that deposits of stream tin have also been discovered. Nearly all the tin produced in Japan comes from the Taniyama Mine, where there are 21 distinct veins, averaging eighteen inches in thickness. These traverse sedimentary rocks composed of soft tuffs, shales and sandstones, with occasional beds of hard, dark blue quartzite. The surface is almost everywhere covered with a deposit of modern pumice, and exposures of volcanic rock are common. The veins course from north-west to south-east; the strike of the rocks is from north-east to south-west, and the ore, which is cassiterite, is

[1] De Launay, *Statistique de la production des gîtes métallifères*, p. 87.

enclosed in a quartzose gangue. One hundred and twenty persons are employed, and the annual production is about eight tons.

In 1874, four mines were producing antimony, but only on a very small scale. Cinnabar occurs in two localities, as impregnations in the sandstones of the Coal-measures.

The silver-bearing veins are, as a rule, true lodes, continuous in depth, regular and persistent. In 1874, ninety-eight mines produced 312,000 oz. of silver, of which one-half was the yield of ten mines. Silver occurs associated with copper and lead ores, and sometimes also with gold. Native silver, argentite, and antimonial silver ore, are the only true silver ores found ; but this metal likewise occurs in fahlerz, in galena, in copper and iron pyrites, and in blende.

Gold occurs in quartz both in veins and in placer deposits, but the latter are uniformly poor. The principal portion of the gold annually produced comes from mines worked chiefly for silver. Mines producing gold alone are, as a rule, not remunerative.

According to the records of the Japanese Mining Office, there were in 1874 no less than 1,856 productive mines in Japan. The following table gives the production of metals in Japan during the year 1875 :—

Production of Metals in Japan, during the Year 1875.[1]

Metals.	Tonnes.	Kilogr.	£
Iron	1,135	—	10,642
Gold	—	376	51,600
Silver	—	9,700	80,496
Copper	3,045	—	185,760
Lead	188	—	4,391
Tin	7	—	619
Total value	—	—	333,058

Compared with the reputed yield of the country in Portuguese and Dutch times, the above table shows a considerable falling off, especially in gold and silver. This is mainly due to the increased value of labour, and to the exhaustion of some of the more easily worked deposits.

[1] *Statistique de l'Industrie Minérale en France*, 1882, p. 200.

The following tables[1] show the production of metals and metalliferous minerals in Japan during recent years :—

PRODUCTION OF THE MINES WORKED BY THE STATE FOR THE YEARS 1887 TO 1893.

Nature of ores.		1887–88.	1888–89.	1889–90.	1890–91.	1891–92.	1892–93.
Gold	Ounces	7,253	8,577	7,659	8,375	7,000	8,802
Silver	,,	198,303	207,446	198,231	225,897	192,265	275,986
Copper	Tons[2]	8·9	19·3	35·1	24·0	17·2	271·0
Iron	,,	3,301	3,921	3,000	3,541	3,103	2,272
Lead	,,	—	—	—	—	—	69
Blue vitriol	,,	—	—	—	341	348	625

PRODUCTION OF THE MINES WORKED PRIVATELY FOR THE YEARS 1887 TO 1892.

Nature of ores.		1887.	1888.	1889.	1890.	1891.	1892.
Gold	Ounces	9,515	10,480	17,050	15,257	15,548	12,738
Silver	,,	94,810	1,168,990	1,184,380	1,477,981	1,697,745	1,640,563
Copper	Tons[2]	10,907	13,176	16,002	17,946	18,722	20,212
Iron	,,	11,763	14,830	17,880	18,573	15,142	17,220
Lead	,,	380	394	593	764	790	807
Antimony	,,	50·7 (with sulphide)	148·7 (with sulphide)	190·5 (with sulphide)	95	62	42
,, sulphide	,,				1,773	2,174	1,324
Tin	,,	94	81	52	47	44	41
Manganese ore	,,	306	799	928	2,559	3,183	4,956
Oxide of tin	,,	4·9	5·8	9·4	7·3	4·8	—
Arsenic	,,	7·8	6·0	4·1	0·3	—	1·0
Copperas	,,	879	1,127	924	935	561	—
Blue vitriol	,,	27	6	64	27	22	—
Mercury	Cwt.	1·6	1·6	18·7	7·1	3·3	293

CHINA.

Very little indeed is known of the mineral wealth of this enormous empire; it produces gold, silver, mercury, copper, tin and iron, but only a few mining districts have been visited by Europeans.[3] The Pingtu Gold Mines in the Shantung Promontory were started under European management about 1886, and closed down some four years later after a fair amount of gold had been got. A shaft was sunk to a depth of 343 feet on a fissure vein of quartz, 4 ft. to 10 ft. thick, running across bedded gneissose formation; the surface quartz was rich and carried much free gold, but in depth pyrites, copper pyrites and galena made their appearance. It was probably the difficulty of

[1] *Résumé Statistique de l'Empire du Japon*, 1895, p. 29.

[2] One *kwan* = 0·003697 tons.

[3] Most of the following information has been taken from "Notes on the rogress of Mining in China," by Ellis Clark, *Trans. Amer. Inst. Min. Eng.* xix 1891, p. 571.

treating these sulphurets, which were, however, rich in gold, that led to the abandonment of the mine.

At Ninghai, in the same province, a vein of quartz, 10 to 80 ft. wide, in granite, carrying gold and iron pyrites, has been extensively prospected and worked to a small extent; according to Mr. Clark, its average gold contents is only about 1½ dwt. to the ton.

The Chao-Yuen district, also in Shantung, presents somewhat similar appearances to the last-named, there being a series of wide quartz deposits in granite, whose average assay value is nearly half an ounce to the ton.

The Chinese also mine gold at Yeshui in Mongolia, north-east from Pekin, the occurrence here taking the form of a network of quartz veins in granite; the ore averages about one ounce of gold to the ton.

Silver-lead too is worked in Mongolia by the Chinese in the Je-hol district at Ten Yung Shang; a strong vein of ore seems to run here east and west, dipping to the north between 50° and 75° in a limestone formation near the contact of the latter with metamorphic schists; in some connection, apparently, with the main vein are a number of very flat-lying deposits in the limestone to the north of the main vein; as has been seen, this is a by no means uncommon mode of occurrence for lead ores in a limestone country. The vein is narrow, and carries rich argentiferous galena and poorer argentiferous blende, the former assaying 300 to 500 ounces, and the latter 12 to 18 ounces of silver to the ton. The Ku-Shan-Tzu Mines, about seven miles east of the last named, present quite similar geological appearances; the vein here has about the same strike and dip, and averages three to four feet wide. The ore is galena with a little tetrahedrite, and assays about 100 ounces of silver to the ton.

There are copper mines at Ping-Chuan-Chao in the same district; the ore seems to occur at the contact of metamorphic limestone and trachyte, and consists of silicate of copper and some copper pyrites.

Various mineral deposits exist in the Chi-Chao district on the Yang-Tsze-Kiang, namely, a lenticular deposit of cupriferous iron pyrites at Tsu-Hung-Tung lying in limestone, and a vein of blende and galena, rather poor in silver, which runs almost perpendicularly with an east and west strike in a country rock consisting of blue slate.

Iron ores occur in many different places. Quicksilver is mined in the province of Kwei-Chan. Tin ore is said to occur plentifully, chiefly in the province of Yunnan, probably in alluvial deposits. Much tin is known to be mined and smelted by the Chinese; the amount has been roughly estimated as between 10,000 and 20,000 tons per annum; none is exported. Antimony ore is also produced. The promontory of Korea is known to be very rich in gold, occurring both as alluvial and as reef gold, the natives working the precious metal in many places. The island of Formosa is also known to be rich in gold.

No statistics respecting the production of China are obtainable. The director of the U.S. Mint in his report for 1894,[1] gives the following as the gold production of China and Korea for the years named:—

Year.	China.	Korea.
1891	10,009 kilogr.	836 kilogr.
1892	12,678 ,,	918 ,,
1893	12,678 ,,	884 ,,

The production of silver is given as nil. The accuracy of these figures may however be considered as greatly open to doubt; the output of Korea is probably a good deal larger than is here represented.

THE AUSTRALASIAN COLONIES.

Victoria.

The chief metallic product of the colony of Victoria is gold, but both tin and copper ores are successfully mined, while ores of lead, antimony, and iron, likewise occur in considerable abundance.

Gold.—The gold of Victoria is derived from three distinct sources, namely, from recent alluvium; from deep leads chiefly of Tertiary age; and from quartz veins. The deposits belonging to the first class require no detailed description, and consist of recent drifts, and surface accumulations actually in course of formation.[2]

The older deposits comprehend drifts of Pleistocene, Pliocene, and probably also of Miocene age, but of these the second are the most numerous and productive. Pleistocene deposits generally

[1] P. 161.

[2] Much valuable information relative to the occurrence of gold in this colony has been derived from Mr. R. Brough Smyth's *Gold-fields and Mineral Districts of Victoria*, Melbourne, 1869.

form the alluvial flats which are found more or less constantly in all the valleys of the gold regions, and through which the streams of the present day have worn their channels. They are composed of gravels, sands, clays and loams, varying in their order of succession, and of which the composition differs in accordance with the nature of the rocks from which they have been derived.

The deeper drifts, chiefly of Pliocene age, have, in many instances, been protected from the action of denudation by a thick covering of basalt. This forms a prominent feature of many of the older leads throughout the colony, as exemplified in the case of the Durham Lead near Ballarat, where the lava has flowed down the course of an ancient valley and covered a river-bed and its accumulated sands and gravels to a depth of nearly 300 feet.

Although a very large proportion of these old river accumulations are of Tertiary age, there would appear to be others still older, even dating from the Carboniferous period.

The quartz reefs of the colony are, for the most part, enclosed in Silurian rocks, which they frequently traverse parallel to their bedding, forming intercalated deposits (compare page 150), while in other cases they intersect them independently of their stratification, forming fissure veins. Gold is not only found in veins traversing granite, felsite and diorite, but is also sometimes disseminated throughout the rocks themselves. It likewise occurs in sandstones, and between the bedding planes of Silurian, Devonian, and other rocks. In veins it is often associated with iron pyrites, galena and other metallic sulphides, as well as with the oxides of iron and manganese, together with calcite, chalybite, carbonate of manganese and bitter spar, and, more rarely, heavy spar. Pieces of fossil wood found in the deeper diggings, as well as fragments of mine timbers from some of the older workings in deposits of this class, have, under the microscope, exhibited, distributed throughout their mass, particles of gold associated with iron pyrites.

The principal mining districts of Victoria are Ballarat, Beechworth, Sandhurst, Maryborough, Castlemaine, Ararat, and Gippsland. In the early days of gold mining in Australia, prior to the discovery of deep leads, and before the working of quartz reefs was begun, the miner was content to wash the sands brought down by rivulets, the soil lying on the slopes of hills, or gold-bearing strata accumulated in valleys. From these shallow placers, which were often immensely rich, has been derived a by no means inconsiderable proportion of the gold produced in Victoria.

The principal gold-fields of the mining district of Ballarat are Ballarat, Buninyong, Creswick, Clunes, Smythesdale, Blackwood, Steiglitz and Gordon, at all which places rich surface gravels and shallow deposits have been found. The shallow diggings at Buninyong and Smythesdale, like those of Ballarat, were once remarkable for the wealth obtained from shallow gullies and from the surface of the hills. At Creswick the shallow alluvium was in many places very rich, and shortly after the field was first opened a party of miners took 145 oz. of gold from the bottom of their shaft; and where a rich patch was struck, it was by no means uncommon to see 12 oz. washed out of one tubful of dirt. The Blackwood gold-fields are situated on the upper tributaries of the Lerderderg River, which have cut deeply into the schists forming their beds. This gold-field offered peculiar facilities to miners with limited capital, inasmuch as no deep sinking was required, nor was any machinery for lifting water necessary, since there is in every part an ample fall for the drainage. The Steiglitz gold-field is situated on the upper waters of Sutherland's Creek, a tributary of the Moorabool River. When these diggings were first opened, about the year 1855, one miner, assisted by a boy, is said to have collected gold to the value of £100 in one month, and nuggets of ten ounces and above were sometimes met with. Gold is found in every part of the Ballarat district where Palæozoic rocks come to the surface.

The principal mining localities of the district of Beechworth are Beechworth, Yackandandah, Chiltren, Wahgunyah, the Upper Ovens, Morse's Creek, Omeo, Wood's Point, Maindample, Alexandra and Ghin-Ghin. This is an interesting district, since it not only contains shallow alluvium, deep leads, and rich quartz veins, but also yields stream tin, and various other minerals, including, occasionally, the diamond. The Beechworth and Yackandandah gold-fields lie within the network of ranges some twenty miles south of the river Murray, and comprehend many tributaries of Kiewa Creek and the Ovens River. In some places masses of granite protrude above the surface, and the detritus of sedimentary strata appears to have been left in basin-like depressions in the granite. Tin ore is found in many places, and in Serpentine Creek the black sand, which is in the proportion of a pound to a panful of dirt, yields gold at the rate of two ounces per ton. The Ovens River is everywhere auriferous; the bed-rock is generally very uneven, and consists of soft yellow sandstone interstratified with hard blue slates. In the Morse's Creek gold-field some very rich claims have been worked. One, taken up by a company of six men, yielded for some time from 60 to 150 oz. of gold per week; and near Harrietville the miners found gold in the ranges at heights varying from 40 to 100 feet above the level of the streams.

The Wood's Point gold-field lies on the northern slopes of the great dividing range which separates the Gippsland waters from

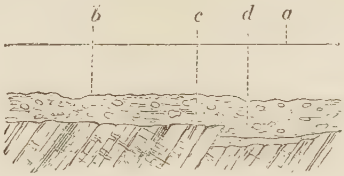


FIG. 107.—Auriferous River-bed; longitudinal section.

those of the Murray district. The formation is schistose, and the rocks, which are usually of Upper Silurian age, are remarkable for being traversed by eruptive dykes and metalliferous veins. Sometimes, although rarely, the gold lies either in a thin layer of sand or pipeclay, or directly on the surface of the bed-rock. More frequently, however, it is met with in the crevices of the rock itself, which, near the surface, is often more or less decomposed, and is broken up by the miner to a depth of from 20 inches to 2 feet. Gold is also found in pot-holes, and where these cavities occur, the bed-rock is usually either a hard schist or a somewhat decomposed granite. When the gold is found either on the surface of the bed-rock, or is embedded in pipeclay, the course of the stream

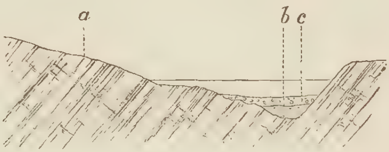


FIG. 108.—Auriferous River-bed; transverse section.

is usually across the strike of the rocks, and the gold, with more or less sand, is chiefly found behind a hard bar, such as that seen in Fig. 107, from *The Gold-fields and Mineral Districts of Victoria*, in which *a* is the surface of the water, *b*, wash composed of large disc-shaped slate pebbles with quartz and a little gold, *c*, bed-rock slate, and *d*, gold associated with sand. In some cases the gold accumulates on one side of a creek, as shown in Fig. 108, in which *a* is the sloping bed-rock of slate, *b*, gold in pipeclay, and *c* ordinary wash consisting of slaty pebbles with fragments of quartz and a little gold. The depth of the wash passed through the washing sluices varies in different localities, and is, to a considerable extent, regulated by the facilities which may be at the command of the miner. Sometimes the whole of the drift, and two feet of the bed-rock, is passed through the washing apparatus, but the gold is chiefly obtained either from the surface of the bed-rock, or from joints in the rock itself.

In the district of Sandhurst, the most important mining localities are Sandhurst, Huntly, Sebastian, Raywood, Kamarooka, Myer's Creek, Bullock Creek, McIvor, Duck Ponds, Redcastle, Rushworth, Whroo, Kilmore, Reedy Creek, King Parrot Creek, and Yea. The gold-fields of Sandhurst are situated on the upper part of the Bendigo Creek, which, for a distance of sixteen miles, runs nearly due north, its basin being bounded on the east and west by low schistose hills running north and south. These throw off numerous spurs, some of which are nearly at right angles to the principal range, while others are approximately parallel. Although now more remarkable for the large yield of gold obtained from its quartz veins than for the value of its alluvial deposits, Bendigo at one time attracted thousands of miners to its shallow diggings, and many tons of gold have been obtained from these deposits. The area of this gold-field is about sixteen square miles, nearly one fourth of which is covered by alluvium. Tertiary drifts also occur at Bendigo. The other gold-fields of the Sandhurst district require no special notice.

The mining district of Maryborough comprehends the gold-fields of Maryborough, Amherst, Majorca, Talbot, Avoca, Lamplough, Amphitheatre, Mountain Hut, Peter's, St. Arnaud, Moonamble Red-bank, Bet-Bet, and several others. The Daisy-Flat Lead at Amherst, which is about seven miles in length and at one point nearly a mile in width, had in its neighbourhood very rich patches of shallow alluvium, derived from a series of parallel quartz veins lying to the south-west. Black Creek, which is a tributary of Deep Creek, has been remarkable for its numerous shallow alluviums, and the aggregate length of all its gullies and flats may be taken at nearly twenty miles. The Amphitheatre and Mountain Hut Diggings are on the sources of the Avoca River, and lie immediately north of a basin having the western spur of the great dividing range for its southern rim. This basin is composed of granite, and the dividing ranges follow very closely the boundaries of the formations. At Lamplough the rich ground occurred in patches, and in one case 108 oz. of gold were here obtained from five loads of wash-dirt. The St. Arnaud gold-field is not less remarkable for its steady yield of gold than for the silver found in veins in the neighbourhood. In this district the operations of the miner are frequently impeded from want of the water necessary for washing the auriferous dirt.

The Castlemaine mining district includes the gold-fields of Castlemaine, Fryers' Creek, Taradale, Yandoit, Hepburn, Daylesford, Blue Mountain, Malmsbury, Anderson's Creek, and the Upper Yarra. The greater portion of the gold-field of Castlemaine is occupied by ranges composed of sandstones, mudstones and slates, which are probably of Silurian age. These rocks are usually not much altered excepting in the immediate vicinity of the granite, where hard fissile slates make their appearance. The strata are everywhere intersected by veins of auriferous quartz, and all the creeks and gullies are filled with recent alluvium, varying in thickness from a few inches to fifty feet. In the vicinity of Red Hill there were four distinct lines of alluvium, the depth at the sides varying from one to six feet, but gradually increasing to fifteen feet to the dip. Here a party of miners took from their claim gold to the value of £30,000, and another found 600 oz. in one pocket; the average yield was about 12 oz. to the tub. Patches of the older drifts occur in many places in Fryers' Creek, but their continuity has been destroyed by denudation. The shallow diggings in this place were once exceedingly rich.

The principal gold-fields of the Ararat district are Ararat, Armstrong's, Great Western, Pleasant Creek, Moyston, Barkly and Beaufort. The greater portion of this district is occupied by basalt and lavas, but west of Wickliffe there is one isolated patch of the older Palæozoic rocks traversed by quartz reefs. A large tract towards the north is occupied by Upper or Middle Palæozoic rocks, with an exposure of granite east of the Victoria range. Still further westward a large mass of granite rises from the centre of an area of gneiss and mica schists; but no gold appears to have been found within this area. The gold-fields of Ararat proper are situated on the eastern slopes of the Mount Ararat Range, which is a small spur of the Coast Range.

Among the many mining localities of the Gippsland mining district are Jericho, Donnelly's Creek, Stringer's Creek, Fulton's Creek, Hawthorn Creek, Red Hill Diggings, Crossover, &c., including the Wonnongatta, Wentworth, and other rivers with their numerous tributaries. Shallow alluvium containing gold occurs on all the tributaries of the La Trobe, whose sources lie in ranges composed of Palæozoic mudstones and shales, among which numerous small gullies and watercourses have at various times given employment to small parties of miners.

Although the precise horizon of the auriferous Tertiaries of Victoria have not, in all cases, been determined with exactitude, it is notwithstanding believed that those hitherto examined have not often been of Pre-Pliocene age. It is also a generally received opinion that no organisms of marine origin have as yet been found associated with any of the gold-drifts of the colony, and although it has been affirmed that marine fossils have been met with in some of the deep leads at Creswick, the statement appears to require confirmation. Generally speaking, deep leads are so covered by thick deposits of sand and other detrital matter that it is rarely possible, from surface indications only, to determine with any degree of certainty either their true position or their approximate extent. This difficulty is materially increased where deposits of this class, as is frequently the case, have become covered by flows of lava. It is true that leads of this kind usually run nearly parallel to the general direction of the existing streams, but minor deviations from such a course are nevertheless numerous. Their depth from the surface is often considerable, and the cost of drainage great. It likewise frequently happens that a lead which has been rich for a considerable distance suddenly widens and becomes unprofitable to the miner, so that the work of prospecting is both costly and uncertain.

When, as at Ballarat, a lead is covered by a capping of basalt, its course can only be determined accurately by expensive underground workings, or approximately by bore-holes. In the deep workings at Ballarat, as well as in various other gold-fields, large trees are often discovered in the black clays overlying the wash-dirt. Excepting on their outer surfaces, the texture of these trees is scarcely altered, and they are often so well preserved as to admit of being readily carved or made up into furniture. The carbonised appearance of the outside of such trees, is probably due to changes effected by the forces which gradually convert forests into coal-seams. As a means of conveying a distinct idea of the nature of the ground passed through in deep sinkings, the following epitome of an account of the workings of the Great North-West Company at Ballarat may not be without interest.[1]

[1] R. Brough Smyth, *The Gold-fields and Mineral Districts of Victoria*, p. 147.

The surface soil was thin, consisting of a few inches of dark mould covering a stratum of sandy loam, at the base of which were found numerous pebbles of brown iron ore. Between this and the first layer of basalt was a bed of yellow sand, varying in thickness from a few inches to two feet. The first basalt, which in some places cropped out at the surface, was found to be 35 feet in thickness, and between this and the second flow of the same rock there were 11 feet of red clay, intersected by numerous vertical cracks, and containing neither fragments of quartz nor vegetable remains. The second layer of basalt was 144 feet in thickness and was usually compact, but somewhat cavernous towards the top. In sinking the shaft, water in considerable quantities was first encountered at the top of this rock, and when the pumping machinery was stopped it rose to a height of 11 feet above this level. Coloured clays, 28 feet in thickness, containing lignite and occasional fragments of quartz, were found beneath the second basalt, immediately beneath which the clay was nearly black, but at a somewhat greater depth it became brown. Below this brown clay came two feet of white clay mixed with sand and fragments of quartz, covering a seam of compact lignite, also two feet in thickness. The colour of the clay beneath the lignite was green. The third layer of basalt, 57 feet in thickness, contained numerous vesicles, and was somewhat columnar in structure.

Beneath the third basalt was a layer of clay about eleven feet thick which at top seemed to be covered with ashes, and on this horizon were found the remains of a large tree. The trunk had the appearance of having been burnt off, while the upper parts had become carbonised, and, when broken, exhibited a glossy fracture like that of charcoal or coal. The roots, which were traced downwards into the clay, showed no indication of the effects of fire, even the smallest rootlets being in a state of remarkable preservation. This clay, excepting quite at the top and towards the bottom, was of a light greenish colour, and was traversed by nearly perpendicular fissures apparently resulting from contraction.

The fourth layer of basaltic rock was struck at a depth of 284 feet, and at the date at which the description was written had been sunk in to a depth of 27 feet. The schistose bed-rock, which had been reached by boring, was found at a depth of 355 feet from the surface, thus showing that the shaft had still to be sunk through a further thickness of 21 feet of basalt and through 23 feet of clay and gravel. The water pumped from deep workings is usually brackish, and is sometimes even decidedly salt.

At Creswick a large tree was found embedded in black clay at a depth of 130 feet from the surface. In these workings the following section was exposed, namely:—

	Feet.
Basalt	100
Sand and gravel	19
Stiff black clay	6
Black drift with fossil tree	5
Total . . .	130

The leaves and trunks of trees, as well as beds of lignite, are of common occurrence in the majority of the deeper drifts of Australia, but they do not appear to have been as yet studied with the amount of attention which could be desired. Some leaves found several years since in the gold drifts beneath the basaltic capping of Table Mountain in California, were submitted to Dr. Newberry, who described them as closely resembling species found in the later Tertiaries of Europe.[1]

In the neighbourhood of Ballarat, as well as in various other regions in Victoria, the Palæozoic rocks have been subjected to extensive erosion by the action of forces which have at the same time effected the disintegration of the original outcrops of the quartz reefs; and these, having undergone a natural process of grinding and washing, have given rise to the formation of drifts containing a much larger proportion of gold than did the veins from which they were originally derived. When, therefore, quartz reefs are intersected by auriferous leads, the wash-dirt is usually, for some distance below the point of their intersection, much richer than elsewhere.

The Duke of Cornwall Company reached the gutter, as the deeper part of a lead is usually called, at a depth of 263 feet 6 inches from the surface, where it was from 60 to 100 feet in width; the thickness of the wash-dirt was about 4 feet, and from about 3,200 cubic feet of stuff 5,000 oz. of gold were obtained.

[1] *Geological Survey of California*, p. 250.

The section of their shaft is thus given:—

	Ft.	In.
Basaltic rock, including surface soil	35	0
Red clay	7	0
Basaltic rock	113	6
Gray clay	9	0
Drift, gravel, and sand	6	0
Basaltic rock	89	0
Wash-dirt	4	0
Total depth to bed-rock	263	6

At Castlemaine and Bendigo, where extensive denudation has taken place, deposits which are the analogues of the deep leads of Ballarat stand out on the surface in the form of bosses. These have frequently been cut through by recent streams, and in such cases the drift in their beds consists partially of the *débris* of these older deposits, and in part of fragments of adjoining quartz-bearing strata. In fact, drifts of three or four different ages may sometimes be observed in the bed of the same stream.

It would be impossible to enumerate the results obtained by any large number of undertakings worked upon deep leads, but in order to convey some idea of their former richness in the vicinity of Ballarat the following examples may be cited. At Gum-Tree Flat a party of six men took out 1,344 oz. of gold in ten weeks, and at the same place another party obtained gold to the value of £24,000 in four months. A third party of eight men, got £20,000 in five months. According to Mr. Wood, who furnished Mr. R. Brough Smyth with a comprehensive statement relative to the operations of some of the more important mining companies then working at Ballarat, forty-two of them had, previous to the year 1869, yielded gold of the aggregate value of £4,305,563.

Mr. Brough Smyth states that he had taken considerable pains to collect authentic information with regard to drifts believed to be of Miocene age, and not supposed to contain gold in sufficient quantities to repay the miner for its extraction. Among other facts bearing upon this subject, attention is called to the circumstance that in sinking the prospecting shaft of the Golden Rivers Company, after passing through a drift containing well-rounded quartz pebbles associated with large quantities of iron pyrites, the miners struck a seam of black clay enclosing fossil trees with a little fine gold, and beneath this was a thick stratum of sandy clay with small fragments of fossil wood. On the bed-rock, composed of a hard yellow sandstone, gold was obtained from every sample washed; and further exploration showed that gold was present wherever the sandstone was laid bare, although not in sufficient quantity to pay for working. The flow of the ancient channel appears to be north-east, and the drift therein deposited is probably of Miocene age.

Sir A. Selwyn gives the following section of the strata near Golden Rivers.[1]

1. Upper basalt, twenty-five to thirty feet.
2. Pliocene gravel, about fifty to sixty feet.
3. Miocene gravel, &c. ("false bottom" of miners), gravel, sand, clay and boulders, with fossil leaves and wood, about 400 feet.
4. Silurian slates, &c.

In a claim at Wombat Hill, Daylesford, a pipe or dyke of basalt was met with which caused the miners considerable trouble and

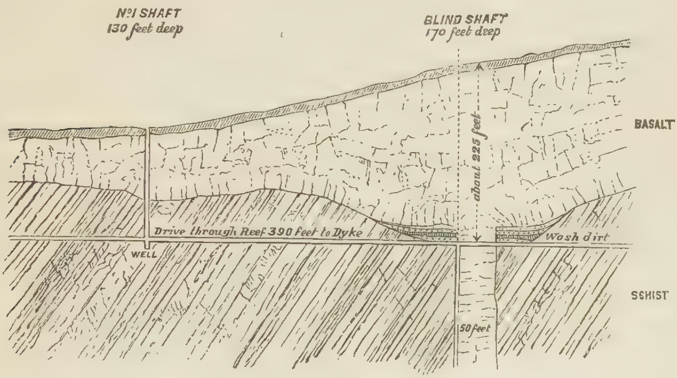


FIG. 109.—Section at Wombat Hill, Daylesford.

expense. Believing it to form a portion of a basaltic capping of the ordinary character, they sunk a winze upon it from the floor of their tunnel to a depth of 170 feet without finding any bottom, but subsequently they drove through it and discovered the gutter on the other side. This dyke (Fig. 109), after R. Brough Smyth, is about fifty feet in width, and the thickness of the overlying capping of basalt 225 feet. It would appear that the drift and neighbouring stratified rocks were but very slightly, if at all, disturbed by the passage of the dyke through them, which, under the circumstances, is somewhat remarkable. The shaft shown in the section was sunk to a depth of 130 feet, and the strata

[1] *Notes on the Physical Geography, Geology, and Mineralogy of Victoria.*

passed through consisted of surface soil, 10 feet; basalt, 80 feet; and Silurian schist, 40 feet. The miners then drove 390 feet east, and there encountered the basaltic dyke, which courses in a south-easterly direction. They afterwards sank 170 feet, following the western limit of the basalt; but, finding it continuous, extended the original south-easterly level, and found the lead on the other side, which abruptly terminated at the edge of the dyke.

In all the gold-fields of Victoria a stratum of ferruginous conglomerate, composed of rounded pebbles of quartz, angular fragments of the same rock, and small pieces of schist, is occasionally found overlying the bed-rock, and touching it in some places, while in others it may be situated from a few inches to several feet above it. At Sandhurst, Maryborough, Castlemaine, in some parts of the Beechworth district, and at Ararat, the cement has been highly auriferous, but its hardness prevents the ready separation of its gold by the ordinary process of sluicing and washing. In fact, in some places it is so hard that blasting has to be resorted to. At Ballarat the cement, which varies from two to eight feet in thickness, occurs as a dark brown mass, consisting of a mixture of pebbles and quartz boulders, united by a cement strongly coloured by hydrated ferric oxide. The hardness of auriferous cement often renders it necessary that it should be sent to the stamp-mill. where it is treated like ordinary gold quartz. At Sandhurst cement occurs in the shallow alluvium as well as in the deep leads, and was in some places very rich. The gold embedded in it is in the form of grains, scales, and small nuggets. In some places these conglomerates have averaged as much as 12 oz. of gold to the ton. As might be anticipated, the distribution of the gold is exceedingly irregular, and at one place in the Ararat district a parcel of 20 tons of cement yielded nearly 360 oz. Some of these conglomerates, as well as the ordinary auriferous drifts of Victoria, contain pebbles and imperfectly rounded grains of cassiterite.

Among the unusually large nuggets which have at various times been found in this colony, the most valuable was the "Welcome Stranger," found near Dunolly, which weighed 2,280 oz. and afforded 2,268 oz. of gold. The next largest, the "Welcome Nugget," was found at Ballarat, at a depth of 180 feet, in June 1858; it was much water-worn, had attached to it about 10 lbs. of quartz, clay, and oxide of iron, and contained 2,166 oz. of gold. The "Blanche Barkly," was found in Kingower, at a depth of 13 feet, and had attached to it about 2 lbs. of quartz, oxide of iron, &c.

This nugget yielded 1,743 oz. 13 dwt. of gold, of the value of £6,905 12*s.* 9*d.* In 1851 a nugget was found by a native among a heap of quartz on the surface of the ground at Meroo Creek, on the Turon river. When discovered it was in three pieces, which together weighed about 1¾ cwt., and consisted of 1,272 oz. of gold with nearly 1 cwt. of quartz. Numerous other nuggets, yielding each above 1,000 oz. of gold, besides almost innumerable smaller ones, have at different periods been found in Victoria, and have been met with at all depths, from the surface of the ground to the top of the deepest bed-rock.

Numerous theories have, at different times, been propounded to account for the origin of nuggets. By one of them it is suggested that they may have grown in the sands and gravels in which they are found, and may even yet be gradually getting larger through the addition of successive layers of gold. Evidence of the presence of gold in the deep leads in a state of solution, and of its subsequent deposition in the metallic state within comparatively recent times, is supposed to be afforded by the auriferous character of some of the pyrites found in the ancient drifts at Ballarat and elsewhere, which, although still retaining the form of roots and branches, contains gold. Mr. H. A. Thompson states that a fine specimen of crystallised iron pyrites, deposited on a piece of wood taken from the drift immediately below the basalt at Ballarat, gave by assay 40 oz. of gold per ton; and in another case, in which iron pyrites from the centre of an old tree trunk was assayed, the yield was at the rate of above 1 oz. 10 dwt. of gold per ton.

An accidental discovery made some years ago by Mr. Daintree, and some more recent experiments by Mr. Wilkinson, are also supposed to be favourable to this hypothesis. Mr. Daintree's discovery consisted in the fact that if a speck of gold be placed in a solution of the chloride of that metal, and a fragment of wood or cork be also introduced, a deposit of gold takes place, and the original fragment gradually increases in size. Mr. Wilkinson's experiments further prove that under similar circumstances iron pyrites, chalcopyrite, mispickel, galena, and various other minerals serve as a nucleus on which a deposit of gold may take place. From this it is argued that the organic matter, so abundant in the drift, may be the agent by which gold has been precipitated from solution. Although this very ingenious theory is worthy of consideration, there would appear to be various points relative to which further information would be desirable, and some of the conclusions would seem to be contrary to observed facts.

Large pieces of gold have been found in quartz veins, and very few large nuggets have been discovered which have not been accompanied by a considerable amount of adhering quartz. That masses of gold of considerable weight have been more frequently met with in drifts than in quartz veins, would be readily accounted for by the fact that the former represent a vastly greater mass of original auriferous quartz than has hitherto been removed by the miner directly from the reefs. In the Garibaldi lands at St. Arnaud a mass of gold weighing 500 oz. was found in a quartz vein, and with it various smaller pieces weighing in the aggregate nearly 400 oz.

The fact that alluvial gold is generally purer than that directly obtained from quartz reefs, has also been used as an argument in favour of their having had a different origin. It is, however, well known that stream tin produces metal of a superior quality to that obtained directly from the mine, and in the same way gold which has been long exposed to the action of water and oxidising influences, will gradually become freed from associated impurities with which it was not combined. Although the purity of alluvial gold is generally superior to that obtained from quartz veins, this is not always the case, and it must be admitted that in the ordinary processes for treating gold quartz, certain impurities with which the metal comes in contact may become alloyed with it and thereby reduce its purity.

A large proportion of the nuggets found occur in the form of pebbles, consisting of a mixture of quartz and gold, presenting a continuous even surface. If, however, in such pebbles, the weight of gold had been augmented by the deposition of successive concentric layers of that metal, a distinct irregularity of the surface might be anticipated, since a growth of quartz exactly equal to that of the gold could scarcely be expected to take place.

If the gold of placers had been deposited *in situ* from solutions, a considerable portion of it would have been crystallised and have formed strings and sheets in the porous material with which it is associated; crystals with entirely unworn edges are, however, never found among placer gold, and strings and sheets of that metal are equally absent.

With regard to uniformity of composition in different parts of the same nugget, Mr. Foord states that he has repeatedly taken samples of different parts of large nuggets with a view of ascertaining the uniformity of their composition or otherwise. Although working with very great care, he had never been able to find a difference in fineness greater than that attributable to working error, say one or two parts in 10,000. Had, however, the results of such experiments differed completely from those obtained, it would not have materially affected the question at issue; since the deposition of gold in veins probably took place by the addition of successive layers; and it will be readily understood that the purity of each may not in all cases have been exactly the same.

It not unfrequently happens that the quartzose veinstone forming part of a nugget exhibits peculiar characteristics, strikingly resembling those of some well-known quartz reef in the approximate vicinity of the locality in which it was found, and from which it would appear to have been originally derived.

On the whole, the balance of probability is perhaps, at present, in favour of the theory which ascribes the origin of gold nuggets to the action of mechanical forces upon the outcrops of veins of auriferous quartz. With regard to deep leads generally, it is manifest that in the majority of cases they owe their preservation to the protective influence of a capping of volcanic rock.

Wherever within the gold-regions of Victoria the Palæozoic bed-rock has been exposed, either by natural denudation by the removal of Tertiary drifts, or by mining beneath the basalt, it is found to enclose auriferous reefs. These, which vary in width from the thickness of a sheet of paper to 150 feet, traverse mudstones and sandstones containing various Palæozoic fossils.

The quartz constituting some of these veins is milk-white in colour, nearly amorphous in structure, and breaks with a somewhat splintery fracture. In other cases the veinstone is more or less stained by ferric hydrate, resulting from the decomposition of iron pyrites. On the other hand, many veins consist of comby or banded quartz, enclosing parallel splintery fragments of the slaty country rock, and containing crystals of pyrites, blende, and other metallic sulphides. The quartz of the more productive veins is either granular or crystalline, and a thin film of gold sometimes occurs between the faces of adjacent crystals. Gold occurs not only in the veinstone of such veins, but also in their casings or selvages, where it assumes the form either of irregular fragments or of more or less perfect crystals.

On sinking upon an auriferous reef a point is reached at a certain depth from the surface where water begins to be troublesome, and at which it constantly maintains its level; among miners this is known as the "water line." Above this horizon the quartz which is usually granular, is often stained by ferric hydrates resulting from the oxidation of iron pyrites; it will also usually contain cavities having a cubical form produced by the decomposition and removal of crystals of pyrites.

These hollows often contain free gold, liberated by the oxidation of the metallic sulphides, which is frequently associated with ochreous iron oxide resulting from the same cause. Cavities of this class have, however, sometimes become partially obliterated by a subsequent growth of quartz in the form of small crystals. Below the water line the metallic sulphides are undecomposed, and often enclose a large proportion of the gold present in the vein. If a fragment of this rock containing gold thus enclosed in undecomposed pyrites, be attacked by nitric acid, the metallic sulphide is dissolved and the gold becomes liberated. Above the water line of the district a nearly analogous change has taken place, through the oxidation of the sulphides and the removal in solution of the resulting metallic sulphates.

There are, however, certain reefs which, although almost entirely composed of metallic sulphides and cropping out at the surface, appear to have undergone but a small amount of decomposition. The stability of iron pyrites and of its various associated sulphides under circumstances in which, if occurring in ordinary quartz veins, they would have been almost entirely decomposed, is somewhat difficult to explain; it must, however, be remembered that in such cases the proportion of sulphides is so large that an amount of decomposition equal to that which takes place in an ordinary quartz vein would scarcely be observable.

The quartz reefs of Victoria sometimes run parallel to the planes of bedding of the country rock, and then belong to the class of bedded or intercalated veins, while at others their course is directed across them, thus forming true lodes. In some instances the same vein may, during certain portions of its course, follow the direction and dip of the enclosing strata, while at others it may cross the bedding nearly at right angles.

An example of a vein of this kind, of which Fig. 110 represents a horizontal section, occurred at Whroo. This vein followed the planes of bedding for short distances, and afterwards repeatedly struck across them at a considerable angle. Both in this vein and in a somewhat similar one in the Caledonia Diggings, the portions marked *a* which cross the strata were not only wider, but also more productive than those marked *b* parallel to the bedding.

In connection with auriferous leads the presence of gold in slate is by no means an uncommon occurrence. A remarkable deposit of auriferous slate was met with some years since at Clunes, where, for a short distance, the vein fissure had not become filled with quartz. The space between the two walls was, however, occupied by rich auriferous slate, the surfaces of which were covered by a thin film of gold. In many cases, true veins crossing the planes of the enclosing country rock throw off branches, parallel to the stratification, which are sometimes rich in gold.

Remarkable formations of gold-bearing quartz, occurring in the form of nearly horizontal deposits, are worked in some localities in Victoria. At the Morning Star, Wood's Point, a dyke of "decomposed granite" underlies to the west, and is traversed by a series of more or less horizontal quartz veins situated one below

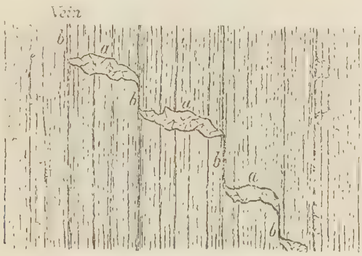


Fig. 110.—Quartz Vein, Whroo.

the other, and having no connection. Portions of the dyke are frequently found enclosed within these veins in the form of horses.

Another remarkable example of the occurrence of quartz in horizontal flats is seen at the Waverley Mine in the same neighbourhood, of which Fig. 111 represents a transverse section. The quartz is here enclosed in a nearly vertical dyke of partially decomposed "greenstone," which runs with the strike of the slate for a distance of a mile and a half. It has two well-defined and nearly parallel slate walls, about three feet six inches apart; and the rock constituting the dyke, besides being much decomposed, is traversed horizontally by bands of quartz varying in thickness from one inch to two feet. Some of these bands have yielded quartz equal in richness to any ever found in the district, and the general average of the whole has been a good one. A feature peculiar to all reefs of this description, so-called *mullocky* reefs, is that, at depths varying from 70 to 200 feet, an undecomposed crystalline rock is met with, which is so hard as to prevent all further sinking. Gold is found in small quartz veins which run through this undecomposed rock in the same way as they occur in the decomposed portions at shallower depths. The *mullock*, or decomposed greenstone, of the Waverley dyke is said to yield small rubies, and is itself to some extent auriferous. The gold from this locality is described as being more than usually pure.

Instead of occurring in dykes of eruptive rock, somewhat similar bands of auriferous quartz have been known to traverse, in almost the same manner, certain bands of slate tilted at a high angle. An example of this class of formation occurs in the Bendigo gold-field, where a seam of graphitic clay, standing at

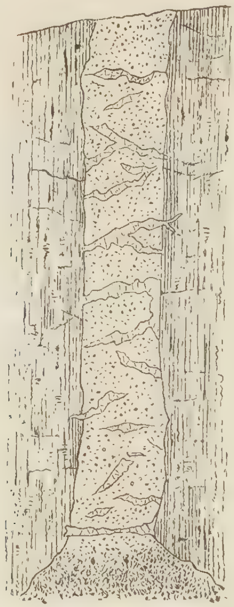


FIG. 111.—Dyke, Waverley; transverse section.

a high angle, follows the direction of the usual bedding of the slate, while, at a distance varying from thirty to forty feet west of it, there is a band of hard sandstone closely resembling quartzite. The space between this band of clay and the sandstone is occupied by a dark slate, similarly bedded, across which lie numerous nearly horizontal beds or floors of quartz. These frequently penetrate for a short distance into the sandstone, but none of them pass into the clay forming the eastern wall. Together these seams form a band nearly 200 feet in depth, which in some places crops out on the surface, and dips gradually towards the north. Some of the quartz veins forming the upper members of this band were exceedingly rich, those near the surface affording above 20 oz. of gold per ton; the yield, however, gradually decreased in depth, while, at the lowest point reached, the slate had become changed into a hard compact rock, and the quartz was comparatively unproductive. At Ballarat it has been observed that whenever quartz veins cross certain narrow beds of pyritiferous slates, known in the district as "indicators," the veins are exceptionally rich at the points of intersection, even though the remainder of the lode be not payable. These indicators are not themselves auriferous, but are a cause of the enrichment of the quartz veins, very much like the fahlbands of Kongsberg in Norway (see page 112) enrich the silver-bearing veins where they intersect them.

The "Indicator belt"[1] is well developed at East Ballarat; one bed is especially known as the "Indicator," but other parallel bands, such as the "western slates," "pencil slates," &c., have the same effect upon the quartz reefs that intersect them. The indicator proper is a thin bed of iron pyrites, parallel to the Silurian strata of which it forms part, and which are here approximately vertical, whilst some of the other indicators are merely narrow beds of slate; the general feature, however, prevails that the quartz reefs within this belt are sometimes nearly horizontal (and therefore cross the stratification at right angles) and sometimes inclined, varying as to their degrees of persistence in extent and thickness, but uniformly rich where they cross the indicators and in the immediate vicinity of their intersections. These indicators are sometimes displaced by lateral faults to as much as several hundreds of feet without affecting their characteristics. So far, the Indicator belt is not known north of Black Hill, but its probable extension northwards is being now traced out.

Mr. Thompson describes reefs of auriferous quartz which he calls "pipe veins," the Achilles Reef at Taradale being cited as a vein belonging to this class. This reef, which at its outcrop is from 20 to 25 feet wide, is 45 feet in length, and has been traced for a considerable distance from the surface without having undergone any material variation in size. This "pipe," which is described as being in connection with a thin, nearly vertical band of quartz sometimes carrying gold, underlies rapidly towards the south, and, although the rock beneath it was sunk through for a considerable distance, no other formation of a similar character was met with. At the surface this vein was exceedingly rich throughout its whole

[1] *Annual Report of the Secretary for Mines for* 1894, p. 22—*Notes*, by Mr. R. A. F. Murray.

width, but as the mine became deeper the gold gradually fell off in quantity, until at length only a few feet on each side were worked, the quartz in the middle being too poor to pay the cost of extraction. The richest quartz was obtained from the foot wall of the deposit. To the east of the vein is a hard crystalline slate, while to the west of it the rock is much softer, and there is no indication of the presence of any other "pipe" of quartz either to the north or south of its outcrop. The string of quartz which occurs in connection with this "pipe" is described as being little more than a joint, with branches of quartz falling into it at intervals, and following the direction and dip of the strata.

The veins of the Victorian gold-fields are represented as frequently exhibiting a tendency to dip in the direction of their bearing, and instances of this peculiarity are stated to occur in every gold-field of the colony. One of the most marked cases of this mode of occurrence is that of the Mariner's Reef at Maryborough, which crops out at the surface in a low range, and, within 1,000 feet of horizontal distance, dips some 650 feet vertically. It is not improbable that further explorations may lead to the conclusion that some of these so-called "pipe veins" are merely sudden local enlargements of ordinary quartz veins, which, like courses of ore in all mining districts, have a tendency to dip in the direction of the course of the vein. Others may be found to be portions of quartz reefs displaced by two nearly parallel faults; and of which the dip has been mistaken for the strike. Some of the reefs at Pleasant Creek, in the Ararat district, present very unusual features. Many of these have been remarkable, not only for their good average yield of gold, but also for their horizontal bed-like mode of occurrence, their extraordinary faults, their peculiar contortions, and their detached and broken masses. Fig. 112 represents a transverse section of portions of the Cross Reef and Flat Reef, which are worked in that locality. The veinstone of the Cross Reef is said to be generally laminated, with a casing upon the hanging wall varying from 6 to 8 inches in thickness. Those portions of the vein in which the quartz does not occur in the form of successive laminæ usually contain but little gold. Mispickel and iron pyrites are abundant in some parts of the reef, and frequently occur in the form of crystalline masses accompanied by gold. This was especially the case at the junction of the two reefs, where the richest specimens of auriferous quartz were obtained, at a depth somewhat above the original water level of the district. The Flat Reef is composed of compact white quartz, without any sort of casing, through which the gold, which is usually coarse, is very unequally distributed. It would appear, however, to be chiefly confined to certain imperfectly defined bands passing through the reef in a northerly direction. In some of these auriferous zones the quartz averaged 7 oz. of gold per ton, but outside of them the yield was usually not more than 3 or 4 dwts. per ton. Both the Cross and Flat Reefs varied considerably in thickness; the former from 3 inches to 24 feet, and the latter from 2 to 8 feet.

A section of the Flat Reef, given by Mr. R. Brough Smyth, shows it to extend for a considerable distance, and to connect the

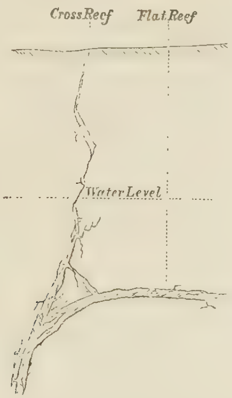


FIG. 112.—Cross and Flat Reefs, Pleasant Creek.

Cross Reef with the Mariner's Reef; no scale is, however, given, and as the description is somewhat general in its character it becomes difficult to clearly understand the exact mode of occurrence of these reefs. Such deposits may probably, in some respects, resemble the metalliferous flats which in many mining districts are associated with mineral veins, or, as has been suggested, their position may sometimes be due to a folding of the strata subsequently to their formation.

The early miners, both in Australia and in California, were generally impressed with the idea that the outcrops of the quartz reefs were more productive than their deeper portions, and this opinion was, to some extent, strengthened by a theory to the same effect promulgated by Sir R. Murchison. Consequently, as soon as the quartz extracted ceased to afford remunerative returns, the miners not unfrequently suspended their operations without extending them to any considerable depth. The experience of the gold-fields of Australia, like those of California and other gold-producing countries, however, shows that there is apparently no fear that the reefs will cease to be productive at any depth to which the miners are likely to follow them.

It is, however, by no means remarkable that the opinion should have got abroad that quartz veins usually become impoverished in depth. Metalliferous veins are exceedingly variable in their yield at different depths, and it will, therefore, be readily understood that those were first operated on which, at the surface, showed evidence of being more or less auriferous. Such veins, after having been followed to a certain depth, may, therefore, be naturally expected to begin to exhibit signs of poverty, and, although sinking deeper might lead to fresh discoveries, the miners in a country in which capital is scarce and wages high, will finally transfer their operations to other outcrops showing a remunerative amount of free gold. Other reasons for the superficial enrichment of metalliferous veins have already been given (see p. 98).

Another cause of the misconception with regard to the poverty of auriferous veins in depth, arises from the fact that, in many cases, the gold is chiefly confined to shoots of auriferous quartz. These, like courses of lead or copper ores, dip in the direction of the strike of the vein, while in other portions of the lode the veinstone is comparatively destitute of gold. Where, therefore, one of these inclined longitudinal courses of auriferous quartz had been worked through and the shaft sunk to a greater depth, the yield naturally fell off, and the mine was often abandoned. Sometimes, however, in consequence of the success of adjoining mines, or from some other cause, the workings were subsequently continued in depth, and another shoot of rich quartz was found. In this way a knowledge of the mode of occurrence of such deposits has been gradually acquired, and at the present time this tendency of auriferous quartz to form diagonal shoots has become fully recognised both in Australia and California, where some of the deepest mines produce, from their lowest levels, quartz as rich in gold as any obtained nearer the surface. The principal quartz veins of Victoria occur in rocks of Lower Silurian age, but are not exclusively confined to that formation. They were generally formed previous to the deposit of the Mesozoic strata, which rest unconformably upon the upturned edges of Palæozoic rocks, which are everywhere penetrated by veins which do not extend upwards into Mesozoic strata. There can also be little doubt that, in at least the majority of cases, the gold was deposited contemporaneously with the quartz, of which the veins chiefly consist. The granites of the colony sometimes contain gold in the vicinity of their junction with the older sedimentary rocks. The direction and dip of the quartz reefs of Victoria are so extremely variable as to admit of no general description.

Some specimens of quartz taken from a vein near Maryborough exhibited features of considerable interest, as they appear to indicate that at least some of the quartz veins of this colony were formed slowly and at low temperatures. Thin fragments of the enclosing slaty rock were found adhering to, and enclosed in, the quartz of this vein, which everywhere presented an exact cast of all the irregularities of the adjacent schist. This schist contained numerous cubical crystals of iron pyrites, and wherever a portion of one of these crystals was partially exposed, either on the surface of the enclosed fragments or on that of the country rock, a perfect cast of it was found in the adjoining quartz.

In a paper read before the Geological Society of London in April, 1872,[1] Mr. Richard Daintree drew attention to the fact that the auriferous Devonian districts of Queensland are entirely confined to such as are penetrated by certain eruptive rocks, principally pyritous diorites. In these diorites, and near the point of their intersection with the Devonian strata, veins of quartz, calc-spar and iron pyrites had been examined and found rich in gold, while the extensions of such veins at any considerable distance from the intrusive rocks were found to be barren. Instances were also adduced to show that the pyrites sporadically distributed through the diorites was occasionally distinctly auriferous, and had, by its decomposition and disintegration, produced drifts containing gold in paying quantities.

In a subsequent communication,[2] Mr. Daintree states that since the date of his first paper he had learned from Mr. C. Wilkinson, then Government Geologist of New South Wales, that the same facts hold good for the New South Wales gold-fields lying in Upper Silurian or Devonian areas; and Mr. G. H. F. Ulrich, the Curator of the Technological Museum in Melbourne, in his catalogue of the rocks in that institution, gives details which go to show that the Upper Silurian rocks of Victoria owe their auriferous character to the same cause.

He describes the diorites of Victoria as occurring mostly as dykes, varying in thickness from a few feet to several hundred, traversing Upper Silurian strata and presenting nearly all the

1 "Notes on the Geology of the Colony of Queensland," *Quart. Jour. Geol. Soc.* xxviii. 1872, p. 271.

2 "Note on Certain Modes of Occurrence of Gold in Australia," *Quart. Jour. Geol. Soc.* xxxiv. 1878, p. 431.

ordinary varieties of structure and composition of that rock. They are nearly always impregnated with auriferous pyrites, and are either traversed by or associated with quartz veins. According to Mr. Ulrich, by far the greater proportion of the quartz gold furnished by the gold-fields occupied by Upper Silurian rocks, is derived from dykes of diorite. In support of these statements he mentions several important workings in connection with dykes of this kind, and especially notices that of Cohen's Reef, which is perhaps the richest in the colony, and the dyke of the Albion Mining Company at Crossover Creek, in North Gippsland, which is interesting on account of its highly micaceous character and its influence on the gold-bearing character of the associated quartz reefs. These, which traverse it nearly at right angles to its strike, are poor in the Upper Silurian rocks on each side, but become richly auriferous throughout the width of the dyke itself, of which the thickness is about ninety feet.

The question as to when the auriferous pyrites was deposited in these diorites is of much interest, and one that it will be somewhat difficult to solve. It is, however, probable that in the majority of cases the pyrites was contemporaneous with the consolidation of the rock in which it occurs, although it is also possible that it may have occasionally owed its origin to the subsequent passage through the rock of metalliferous solutions. A large number of sections of pyritous diorites, felsites, and granites, were examined under the microscope by Mr. Daintree, who, in a few instances only, found portions of the enclosing rock embedded in crystals of pyrites.

Below the water level, which usually very nearly coincides with the zone of decomposition, veins of a class which on the whole has proved very misleading to the miner, although often rich in gold, usually disappear. These follow the lines of jointing of the rock, and are probably due to the decomposition of auriferous pyrites in the eruptive rock and the re-deposition, from solution, of a portion of its material in local fissures. It is probable that to this mode of formation are to be attributed the horizontal veins described as occurring at Waverley and elsewhere. Besides the veins above referred to, there are, associated with the intrusive auriferous rocks, others which Mr. Daintree considers as being of far greater practical importance from being generally of greater width and more likely to be persistent in depth. These he regards as the result of hydrothermal agencies which preceded and accompanied the protrusion, and which in some cases continued long after the intrusive rock had cooled down.

The production of gold in Victoria from its discovery in 1850 to 1895 has been as follows :—

TABLE SHOWING WEIGHT AND VALUE OF GOLD PRODUCED IN VICTORIA FROM 1851 TO 1895 INCLUSIVE.[1]

Year.	Alluvial.	Quartz.	Together.	Value at 80s. per oz.
	oz.	oz.	oz.	£
1851 { Three Months			212,899	851,596
1852			2,286,535	9,146,140
1853			2,744,098	10,976,392
1854			2,218,483	8,873,932
1855			2,819,288	11,277,152
1856			3,053,744	12,214,976
1857			2,830,213	11,320,852
1858			2,596,231	10,384,924
1859			2,348,703	9,394,812
1860			2,224,069	8,896,276
1861			2,035,173	8,140,692
1862			1,730,201	6,920,804
1863			1,694,819	6,779,276
1864			1,622,447	6,489,788
1865			1,611,554	6,446,216
1866			1,546,948	6,187,792
1867			1,501,446	6,005,784
1868	1,087,502	597,416	1,684,918	6,739,672
1869	934,082	610,674	1,544,756	6,179,024
1870	718,729	585,575	1,304,304	5,217,216
1871	698,190	670,752	1,368,942	5,475,768
1872	639,551	691,826	1,331,377	5,325,508
1873	504,250	666,147	1,170,397	4,681,588
1874	433,283	664,360	1,097,643	4,390,572
1875	426,611	641,806	1,068,417	4,273,668
1876	357,901	605,859	963,760	3,855,040
1877	289,754	519,899	809,653	3,238,612
1878	264,453	493,587	758,040	3,032,160
1879	293,310	465,637	758,947	3,035,788
1880	299,926	529,195	829,121	3,316,484
1881	313,828	519,550	858,850	3,435,400
1882	352,078	512,532	864,610	3,458,440
1883	304,666	475,587	780,253	3,121,012
1884	326,305	452,313	778,618	3,114,472
1885	281,818	453,400	735,218	2,940,872
1886	248,356	416,840	665,196	2,660,784
1887	228,894	388,857	617,751	2,471,004
1888	238,634	386,392	625,026	2,500,104
1889	229,854	384,984	614,838	2,459,352
1890	206,159	382,401	588,560	2,354,240
1891	188,547	387,852	576,399	2,305,576
1892	201,959	452,497	654,456	2,617,824
1893	218,673	452,453	671,126	2,684,504
1894	254,309	419,371	673,680	2,694,720
1895	279,903	413,934	740,086	2,960,344
Totals	—	—	61,186,321	244,745,284

[1] The figures given previous to 1868 are the amounts and values of the gold exported only, and are consequently under the truth. Those for 1868, and for

According to the mineral statistics of Victoria for the year 1880, the approximate area of auriferous ground over which mining operations had extended up to the end of that year was 1,235¼ square miles, and the number of distinct reefs proved to be auriferous 3,630. The deepest shaft in the colony, at Stawell, was 2,410 feet deep; at Sandhurst there was a shaft 1,476 feet deep, at Maldon one of 1,220 feet from the surface, and at Clunes two shafts were respectively 1,193 and 1,105 feet deep. The average fineness of the gold of Victoria is nearly 942.

During the year 1880, 31,456 tons of quartz obtained from the Ballarat mining district, at depths varying from 200 to 1,105 feet from the surface, yielded from 6 dwt. 1 gr. to 14 dwt. 11 gr. of gold per ton; 2,770 tons of quartz, taken from depths varying from 200 to 600 feet, from the Beechworth district, yielded from 8 dwt. to 4 oz. 16 dwt. 7 gr. of gold per ton; 17,216 tons of quartz obtained at Sandhurst, at depths varying from 400 to 1,267 feet, yielded from 13 dwt. 11 gr. to 2 oz. 9 dwt. 22 gr. of gold per ton; 15,112 tons of quartz from the Maryborough district, obtained at depths varying from 305 to 680 feet, yielded from 12 dwt. 6 gr. to 6 oz. 13 dwt. 3 gr. of gold per ton. In the Castlemaine mining district, 6,202 tons of quartz obtained at depths varying from 200 to 500 feet, yielded from 18 dwt. to 3 oz. 17 dwt. 3 gr. of gold per ton; 6,281 tons of quartz obtained at Stawell, at depths varying from 612 to 1,200 feet, yielded from 1 oz. 6 dwt. to 4 oz. 12 dwt. 16 gr. of gold per ton. At Stringer's Creek, in the Gippsland mining district, 19,621 tons of quartz, obtained at depths varying from 343 to 723 feet below adit, yielded from 1 oz. 4 dwt. 22 gr. to 1 oz. 6 dwt. 22 gr. of gold per ton.

These figures may be contrasted with those returned for 1894 and 1895. The deepest shafts at that time were all situated in the Bendigo (or Sandhurst) district, the deepest being Lansell's 180 Mine, 3,352 feet in the beginning of 1896, New Clunes Consolidated Company 2,905 feet, New Clunes and Victoria Company 2,990 feet, and Lazarus Company 3,024 feet. At Ballarat the South Star was 2,030 feet deep, and the Star of the East 2,024 feet in the beginning of 1896, and at Clunes, the Port Phillip, which had been idle for some time, was 1,746 feet deep.

The following table shows the part played by the various districts in the gold production for 1894:—

subsequent years, represent the actual production as calculated by the Mining Surveyors and Registrars. They are taken from *The Mineral Statistics of Victoria* ("Annual Report of the Secretary for Mines").

District.	Alluvial.		Quartz.		Total.	
	Men employed.	Gold got.	Men employed.	Gold got.	Men employed.	Gold got.
		Oz.		Oz.		Oz.
Ballarat	2,219	76,269	4,098	118,551	6,317	194,820
Beechworth . . .	2,685	71,084	1,498	24,911	4,183	95,995
Sandhurst . . .	417	8,065	3,898	151,646	4,315	159,711
Maryborough . .	3,015	44,256	1,313	20,131	4,328	64,387
Castlemaine . . .	2,696	32,090	1,800	32,797	4,496	64,887
Ararat	776	10,728	703	16,863	1,479	27,591
Gippsland . . .	1,211	11,816	1,560	54,473	2,771	66,289
Totals . . .	13,019	254,308	14,870	419,372	27,889	673,680

Complete returns as to the yield of the stone are not obtainable; the following are the quantities of quartz crushed that were reported by the districts named:—

Ballarat	303,145	tons.
Beechworth	27,924	„
Sandhurst	394,712	„
Castlemaine	64,346	„
Ararat	30,414	„
Gippsland	40,507	„
Total	861,048	tons.

Altogether crushings were reported of 898,506 tons, which yielded 374,714 ounces, being at the rate of 8 dwt. 8 gr. per ton of stone. This is the lowest yield yet recorded. In 1885 the yield was at the rate of 10 dwt. 1 gr., and the average from 1885 to 1893 was 9 dwt. 13 gr. The average richness of all the quartz treated since the commencement of mining in Victoria was returned in 1894 as 10 dwt. 5 gr., that of the tailings and "mullock" as 2 dwt. 22 gr., and that of the concentrated pyrites 2 oz. 4 dwt. 16 gr.; it is evident that these two latter figures represent gold that was indirectly obtained from the quartz reefs, but there are no authentic data that show by how much the yield per ton of the quartz should be thereby increased.

The average richness of the wash-dirt, of which particulars have been recorded, was in the same way 1 dwt. 12 gr., and that of the cement 4 dwt. 0 gr. per ton.

The diminution in the richness of the ore treated does not necessarily mean that the deposits become poorer in depth; it may more probably be due to the fact that improvements in the methods of mining and of gold extraction have so cheapened these operations that poorer material can now be profitably worked than was formerly the case. In 1895 there were altogether 29,897 men engaged in gold mining. Crushings were reported of 855,736 tons of quartz for a total yield of 368,035 ounces, being at the rate of 8 dwt. 14 gr. to the ton. Of wash-dirt there were 1,398,084 tons treated, producing 111,014 ounces of gold, and of cement 16,008 tons, producing 1,380 ounces.

Silver.—Argentiferous galena and embolite are found at St. Arnaud, associated with iron pyrites, mispickel, chalcopyrite, malachite, native copper, native silver, gold, cerussite, anglesite, mimetesite, blende, native sulphur, brown iron ore and oxide of manganese. Some of the stibnite of Victoria has been found to contain silver in the proportion of 80 oz. per ton. Embolite is found at St. Arnaud in cavities in drusy quartz above the water level, and is probably a secondary product resulting from the decomposition of argentiferous galena. Silver ores likewise occur at Ararat, Pleasant Creek, Morse's Creek, Sandhurst, Heathcote, Reedy Creek, and elsewhere.

During the year 1880 no silver ores were raised, but 169 oz. 15 dwt. of that metal were parted from gold in the St. Arnaud district, and 23,078 oz. 15 dwt. were parted from gold melted at the Melbourne mint. The total yield for the year was, therefore, 23,248 oz. 10 dwt. The production of silver except as parted from gold has always been quite insignificant. The amount obtained in this way in 1888 was 27,332 ounces, and since then it has remained about stationary, and may be taken as between 25,000 and 30,000 ounces yearly.

Lead.—Galena occurs in many of the reefs at Sandhurst; near Blue Mountain, with malachite and yellow copper ore; in Gippsland; in Campbell's Reef at Moyston; at St. Arnaud; and in various other localities. Although it is of common occurrence, this mineral has not been anywhere obtained in large quantities. Below the water level of St. Arnaud it is, however, sometimes met with in the form of strings and patches. It is always argentiferous, and at St. Arnaud contains above 100 oz. of silver per ton. No lead ore was raised in Victoria during the year 1880, and the amounts have always continued insignificant; up to 1893 a total of 753 tons had been produced; in 1890, 50 tons, valued at £50, were obtained, and none at all in 1894.

Copper.—Native copper is found in some of the St. Arnaud veins, and the green and blue carbonates of that metal occur, above water level, in many of the reefs throughout the colony. Copper pyrites is found in diorite on the Thompson River, about five miles south of the junction of that stream with Stringer's Creek. The vein is said to be sometimes as much as 35 feet in width. Mining operations were in progress in this place as early as 1868, and smelting furnaces had been erected on the opposite bank of the river. According to official returns, 3,030 tons 10 cwts. of copper ore were raised in the colony during the year 1880, and 3,938 tons were smelted; 262 tons of copper and 17 tons 11 cwts. of regulus were exported. Up to the end of 1893, a total of 16,953 tons of copper ore had been produced; the output for 1894 was 484½ tons, valued at £14,762.

TIN.—The alluvial tin ore obtained during the year 1880 amounted to 103 tons 10 cwts. Stream tin is found in the Beechworth district, in the tributaries of the Lerderderg, at Gympie near Steiglitz, in the tributaries of the River Yarra, in the basin of the River Thompson, and in many of the feeders of the Latrobe River, &c. During the year 1882, 1,077 tons of tin ore were produced. The more recent finds at Wombat Creek Omeo, and at Mount Wills, in which latter place tin is also found in veins and disseminated in granite, forming a true stockwork, were at one time looked upon as very hopeful. Nevertheless, the tin production of Victoria has never yet assumed important dimensions. One of the best years was 1891, when 1,778 tons of ore, valued at £5,092, were obtained. In 1894 only 60 tons were raised, and at the end of that year the total tinstone produced in the colony since the commencement of tin mining was returned as 14,481 tons.

ANTIMONY.—Stibnite, with valentinite and other oxidised ores of antimony, occurs in various places in the colony. At Whroo very remarkable concretions are found in the veins. They assume the form of concentric layers of differently coloured oxides surrounding a central nucleus of sulphide of antimony. All through the oxidised portions gold is disseminated in the form of ragged grains varying in size from a mere speck to pieces as large as a pea. A vein containing sulphide of antimony was discovered some years ago at Munster Gully, Dunolly; and at Donovan's Creek, on the Upper Yarra, a lode, varying from one foot six inches to two feet in width, consists almost entirely of bright and nearly pure stibnite. At Sunbury there is a vein consisting chiefly of quartz and sulphide of antimony; this has an irregular course chiefly along the strike of the Silurian strata, but in some places crossing them obliquely. In addition to antimony, this lode, which varies in thickness from 3 to 18 inches, contains about 2 oz. of gold per ton. Another vein of auriferous antimonial ore is said to occur only seventeen miles from Melbourne. The antimony mines of Costerfield were discovered many years ago, and have been since wrought with varying success. During the year 1880 there were raised 333 tons 17 cwts. of antimony ore, of which 272 tons 17 cwts. were smelted in the colony, and from which 178 tons 10 cwts. of regulus were obtained; 85 tons of antimony ore and 323 tons of regulus were exported. During the year 1882, 375 tons of antimony ore were raised. In 1894 the output had fallen to 35 tons, valued at £175. The total production of the colony up to the end of that year is returned as 22,807 tons.

The following table[1] shows the production of metallic minerals other than gold in the years 1894 and 1895, and the total amount produced in Victoria up to the end of 1895:—

PRODUCTION OF METALLIC MINERALS OTHER THAN GOLD IN VICTORIA, FOR THE YEARS 1894 AND 1895, AND TOTALS OF THE SAME.

Mineral.	For 1894.		For 1895.		Total to end of 1895.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Tons.	£	Tons.	£	Tons.	£
Copper ore . . .	484½	14,762	7	210	17,444¾	206,395
Tin ore	60	2,286	74½	3,133	14,555½	687,739
Antimony ore . .	35	175	—	—	22,806¾	176,644
Lead ore	—	—	20	100	773¼	5,519
Iron ore	—	—	—	—	5,434½	12,540

NEW SOUTH WALES.

In addition to its pastoral and agricultural resources, New South Wales is rich in minerals, yielding, besides coal and so-called oil shales of exceptionally good quality, gold, silver, copper, tin, and other metals. This is the oldest of the Australian settlements, having been first colonised in the year 1788. Among its principal mining districts are Albert, Bathurst, Cobar, Tambaroora and Turon, Mudgee, Lachlan, Southern Tumut and Adelong, Peel and Uralla, Hunter and Macleary, and New England and Clarence.

GOLD.—Gold occurs in New South Wales, under conditions

[1] *Annual Report of the Secretary for Mines*, 1895.

almost precisely identical with those characterising the auriferous deposits of the adjoining colony of Victoria. It is found in recent alluvium, in leads of Tertiary age, and in quartz veins; in addition to these deposits, the lowest beds of the Coal-measures, which, north of Gulgong, cover a large area of country, are sometimes remuneratively auriferous. The existence of these ancient conglomerates containing gold, appears to indicate that at least some of the auriferous quartz reefs of Australia were formed prior to the Carboniferous period. The Rev. W. B. Clarke speaks of a lump of gold having been found in a mass of coal, and states that much of the gold in New South Wales has been derived from iron pyrites, diffused through granite and various beds of sedimentary origin, consisting of siliceous materials cemented by oxide of iron resulting from the decomposition of pyrites. Daintree, Hacket, Wilkinson, and others have shown that a large portion of the gold in Victoria and Queensland is due to the agency of intrusive dykes of felstone, elvan and diorite, so that reefs of quartz in Silurian rocks are not, as was at one time supposed, the exclusive source of Australian gold.[1] At Timbarra gold is found in granite; these gold-fields consist of a granitic tableland, traversed by dykes of eurite and pegmatite, also occasionally showing veins of auriferous quartz, which may possibly be segregation deposits. The weathered granite is sluiced, and very fine gold, to the extent at times of 5 dwt. to the ton, is obtained. Gold has been found to occur here in unaltered granite, and in eurite, as well as in the decomposed granite.[2]

Many of the deep leads are here, as elsewhere, covered by flows of basalt, and sometimes enclose, not only vegetable remains, but also fossil insects. At Montreal, on the south-eastern side of Dromedary Mountain, a discovery of gold has been made immediately upon the sea coast. This field contains rich deposits of water-worn gold, which has evidently been reduced to its present condition by the action of the sea, by which it has been arranged in two distinct terraces, of which the lowest is somewhat above the present high-water mark.

The Wyalong gold-field has been carefully studied by Mr. E. F. Pittman,[3] who finds that the geological features of the district are

[1] *Mines and Mineral Statistics of New South Wales*, Sydney, 1875, p. 153.

[2] G. W. Card, "On some Rock Specimens from the Auriferous Granite at Timbarra," *Records Geol. Survey of N.S.W.* 1895, p. 154.

[3] "On the Geological Structure of the Wyalong Gold-fields," *Records Geol. Survey of N.S.W.* 1894, p. 107.

hard, highly metamorphic and steeply inclined slates, sandstones and quartzites, probably of Silurian age, with intrusive hornblendic granite, diorite, and felsite, together with bosses of solid micaceous granite. All the granite is greatly decomposed at the surface, and down to a depth of, at any rate, 200 feet, the lowest point at which it has been penetrated by a shaft. The reefs appear generally as narrow threads at the surface, which widen out as they go down; less often they are wide at the surface, then pinch, and finally widen out again at still greater depths. They are, in fact, lenticular reefs, formed, according to Mr. Pittman, by the fissuring of the granite with undulating surfaces, the subsequent movement up or down of one wavy face upon the other having produced these lenticular forms. (Compare page 70.) The quartz has been deposited in these fissures by the percolation of waters carrying silica in solution. It may be noted that both horses of country rock and faults are common in the district. The general course of the reefs is N. 20° E., with an easterly dip, and their width varies from an inch or two to several feet. One reef on this field runs in slate between two diorite dykes. Mr. Pittman regards the hornblendic rocks as the immediate source of the gold at Wyalong, but assigns no reason for this opinion, although he makes the very important statement that the occurrence of such hornblendic rocks in proximity to reefs of gold-quartz is characteristic of the New South Wales gold-fields (see also page 641). It does not appear whether gold has been proved by assay to exist in these rocks or not.

The quartz reefs of New South Wales, like those of Victoria, often run parallel to the bedding of the enclosing rocks, but they nevertheless sometimes cross it at considerable angles. Occasionally tin oxide is found in the same veinstone. Some of the quartz reefs of New South Wales have, for limited distances, been exceedingly rich. Masses of auriferous material which were nearly all gold, weighing about 100 lbs. each, were blasted in 1872 at a considerable depth from a vein at Hill End. One claim yielded 30,000 oz. of gold from 436 tons of quartz, and another produced 1,567 oz. of gold from 22 tons.[1] Such yields are, however, quite exceptional, as the average produce of the quartz treated in 1880 amounted to only 15 dwt. 17·54 gr. of gold per ton. At the close of the year 1880 the depth of the deepest shaft in the colony was 840 feet. The auriferous area is approximately estimated at 7,000 square miles.

[1] T. Richards, *New South Wales in* 1881, p. 63.

The following table[1] shows the annual production of gold in New South Wales from the date of its discovery in 1851 to the end of 1895:—

TABLE SHOWING WEIGHT AND VALUE OF GOLD PRODUCED IN NEW SOUTH WALES FROM 1851 TO 1895 INCLUSIVE.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Oz.	£		Oz.	£
1851	144,120	468,336	1874	270,823	1,040,329
1852	818,751	2,660,946	1875	230,882	877,694
1853	548,052	1,781,172	1876	167,411	613,190
1854	237,910	773,209	1877	124,111	471,418
1855	171,367	654,594	1878	119,665	430,033
1856	184,600	689,174	1879	109,649	407,219
1857	175,949	674,477	1880	118,600	441,543
1858	286,798	1,104,175	1881	149,627	566,513
1859	329,363	1,259,127	1882	140,469	526,522
1860	384,053	1,465,373	1883	123,805	458,509
1861	465,685	1,806,171	1884	107,198	395,292
1862	640,622	2,467,780	1885	103,736	378,665
1863	466,111	1,796,170	1886	101,416	366,294
1864	340,267	1,304,926	1887	110,288	394,579
1865	320,316	1,231,243	1888	87,503	317,100
1866	290,014	1,116,404	1889	119,759	434,070
1867	271,886	1,053,578	1890	127,760	460,285
1868	255,662	994,655	1891	153,336	558,306
1869	251,491	974,149	1892	156,870	569,178
1870	240,858	931,016	1893	179,288	651,286
1871	323,609	1,250,485	1894	324,787	1,156,717
1872	425,129	1,643,582	1895	360,165	1,315,929
1873	361,784	1,395,175			
Totals				11,394,562	42,326,588

Like the other Australian colonies, New South Wales sometimes suffers from prolonged droughts, and the supply of water available for mining purposes materially affects the amount of gold obtained during each year. The average fineness of the gold of New South Wales may be taken at about 876.

The great increase in gold production in 1894 is due not to any discoveries of new fields, but to administrative measures, chiefly to the policy of giving large numbers of unemployed working men facilities for reaching the various gold-fields, and enabling them to go to work on them. The following table,[2] although incomplete, will give a good idea of the degree in which the respective districts contribute to the total production of gold:—

[1] *Annual Report of the Department of Mines for* 1895, p. 16.

[2] *Annual Report of the Department of Mines for* 1894, p. 70.

District.	Number of miners.			Quantity of gold got.			Value of gold got.	Auriferous ground worked.	Quartz reefs found to be auriferous.	Value of machinery.
	Alluvial.	Quartz.	Total.	Alluvial.	Quartz.	Total.				
	No.	No.	No.	Oz.	Oz.	Oz.	£	Sq. M.	No.	£
Albert	260	74	334	3,587	4,179	7,766	25,548	15	1	1,997
Bathurst	1,342	833	2,175	9,021	41,003	50,024	178,500	130	50	109,029
Clarence and Richmond	494	111	605	1,488	1,398	2,886	10,551	1,918	124	12,250
Cobar	—	685	685	—	20,593	20,593	78,469	18	9	12,100
Hunter and Macleay	20	168	188	190	769	959	3,371	16	11	7,074
Lachlan	1,449	3,511	4,960	10,063	21,043	31,106	115,072	170	100	51,943
Mudgee	972	532	1,504	10,432	18,007	28,439	106,335	121	45	44,550
New England	295	118	413	3,270	3,395	6,665	22,954	288	2	4,150
Peel and Uralla	993	1,017	2,010	6,724	39,241	45,965	164,208	22	44	110,491
Tambaroora and Turon	687	350	1,037	8,767	2,678	11,445	44,233	77	85	21,900
Tumut and Adelong	1,127	735	1,862	7,502	9,813	17,315	63,598	146	90	50,550
Southern	1,103	331	1,434	10,219	13,523	23,742	88,137	140	86	118,885
Totals	8,742	8,465	17,207	71,263	175,642	246,905	900,976	3,061	647	544,919

Crushings have been reported of 149,514 tons of quartz which yielded 107,189 ounces of gold, being at the rate of 14 dwt. 8 gr. per ton, a lower yield than that obtained in the preceding year. For 1895 [1] far higher results are returned. Crushings are recorded of 128,431 tons of quartz, which yielded 173,807 oz., or at the rate of 1 oz. 7 dwt. 1 gr. per ton. This abnormally high result is due to a great improvement in the yield in the Bathurst district, where 17,541 tons produced at the rate of 4 oz. 15 dwt. 17 gr. per ton. In 1895 there were 10,103 men engaged in quartz mining, and the yield from this source is given as 246,152 oz. In 1894 the alluvial mines treated 112,989 loads of wash-dirt for a return of 3,898 oz. of gold, being at the rate of 17 gr. to the ton. It may be added that the Broken Hill Proprietary Silver Mining Company obtained 4,079 oz. of gold in the course of their smelting operations in 1894. In 1895 the average yield of wash-dirt is given as 6 dwt. 5 gr., but the return is far too incomplete to be of any value. There were 11,331 men engaged in alluvial mining, and 72,158 oz. of gold are returned as having been obtained from this source.

Silver.—Very little attention had been paid to silver mining previous to 1885, when regular work was commenced upon the rich deposits in the Barrier Range; these have produced silver upon so large a scale as very materially to affect the silver market of the world. Before this time discoveries had been made at Boorook and a few other localities, none of which can be considered as being serious factors in the silver production of the colony in

[1] *Annual Report for* 1895, pp. 33, 77.

1895, the returns from all other sources being swamped by the immense production of the Barrier Range.

The Boorook silver mines are situated in a hilly country twenty-six miles north-east of Tenterfield, and are worked upon lodes chiefly enclosed in sedimentary rocks, some of which are highly metamorphosed. The main range of granite is distant from two to three miles from the mines, and porphyries and crystalline schists occur in their immediate neighbourhood. The fossils enclosed in some of the stratified rocks indicate that they are of Upper Devonian age. The veins are numerous and traverse a considerable extent of country, but have only been explored by comparatively shallow workings. Their general strike is east of north and west of south, while their dip is usually towards the south. Samples of the ore have yielded by assay as much as 522 oz. of silver per ton. The appliances available for the reduction and treatment of the ores are represented as having been inadequate to the requirements of the district, and the development of the mines has been much retarded in consequence.

Argentite appears to be one of the principal sources of silver, but pyrargyrite and horn silver are likewise present, the associated minerals being iron pyrites, chalcopyrite, galena, blende and oxide of iron. The veinstone is principally quartz, and always contains a certain amount of gold, the proportion found in the samples assayed varying from 5 gr. to 18 oz. per ton. No constant relation appears to exist between the relative amounts of gold and silver present in different samples. According to Mr. Davey, at depths of less than eighty feet from the surface the silver occurs chiefly in the form of chloride, and is therefore readily obtained by amalgamation ; while below that point the ores require a preliminary roasting with salt. Mr. Davey remarks that argentiferous iron pyrites carrying gold would have been most efficiently treated by smelting with lead ores, had the necessary plant and fuel been available.

The most important silver mine of the district is the Golden Age, which is worked in a buff-coloured clay slate situated about two miles from the granite. The lode courses about 22° E. of N., has a dip towards the west, and to a depth of about eighty feet averages about twelve inches in width. From the surface down to this level the most abundant ore was chloride of silver, with some argentiferous pyrites. The whole of the lode to this depth has been stoped away, and all the chlorides have been exhausted. About 52,000 oz. of silver and 250 oz. of gold were obtained from this portion of the lode. There were three shafts at this mine in 1881, the deepest of which reached 130 feet below the surface. For the last fifty feet the average width of the lode was from eighteen to twenty inches, with a band on either side of rich argentiferous pyrites. This pyrites contains silver in the proportion of from 70 to 150 oz. per ton; but at the bottom of the mine the centre of the lode consists mainly of a slaty breccia, which is by no means rich. A mixture of iron pyrites with blende is often rich in the precious metals, specimens of this kind sometimes yielding as much as 800 oz. of silver and 5 oz. of gold per ton of stuff.

The light-coloured clay slate referred to as forming a portion of the country rock of the Golden Age Mine, does not appear to extend beyond the limits of that property. About fifty yards south of the deepest shaft, situated nearly in the centre of the mine, the lode is intersected and displaced by a flucan containing a few lenticular masses of quartz, which, near the surface, were extremely rich in silver. The country rock west of this cross-course differs materially from that of the Golden Age Mine, consisting as it does of a blue fossiliferous slate, whereas on the eastern side no fossils have as yet been found. Below the depth of eighty feet the rock becomes a blue slate which is compact, and is not known to contain fossils. The lode gradually became richer as it approached the cross-course, and was very productive in its immediate vicinity. During the year 1880, rather more than 30,000 oz. of silver were returned from the Golden Age Mine, and nearly 2,000 more from the Addison Lode, Simmons and Donaldson's claim. There were no returns from this district in 1894.

The Barrier Range is a dry barren mountainous district in the north-eastern extremity of New South Wales. Silver-lead ore seems to have been first found here in 1876,[1] and lodes were found from time to time, together with very rich float stones of horn silver. In 1883 the Broken Hill lode was pegged out, and about August 1885 the Broken Hill Proprietary Silver Mining Company was formed. The formations composing the Barrier Range consist of Pre-Devonian (possibly Silurian) slates, limestones, sandstones and micaceous schists, striking about north and south, dipping at steep angles and penetrated by bosses and dykes of granite and dykes of felsite, diorite and basalt. Alluvial gold and tin have been found within the limits of this district, also lodes of copper, in addition to the rich silver lodes which are the principal objects of exploitation. The main Broken Hill lode has already been described (*see* p. 158), and its peculiar form, namely that of a

[1] Most of this information is derived from J. B. Jaquet's valuable monograph on the "Geology of the Broken Hill Lode and Barrier Ranges Mineral Field," *Memoirs of the Geol. Survey of N.S.W.*, "Geology," No. 5, 1894.

saddle lode, has been pointed out. There are three other lodes all approximately parallel, the Eastern, North Eastern, and the Western Lodes, each of which may possibly be one leg of a parallel saddle lode, the other leg of which has either been suppressed or else denuded away. These other lodes may possibly also be ordinary bedded lodes. Besides these, the Australian Broken Hill Consols is working on a narrow lode which seems on the other hand, according to Mr. G. Smith,[1] to be a fissure vein and to differ in many respects from the previous ones.

The Broken Hill Proprietary Company has practically confined its operations to the main lode, and the largest portion of the ores hitherto extracted have consisted of oxidised ores of various kinds. A large amount of a manganiferous and ferruginous ore, carrying from 7 to 45 oz. of silver to the ton and about 18 per cent. of lead, has been mined, which formed the cap or gossan of a large portion of the mine. There are also rich carbonate of lead ores, containing 5 to 80 oz. of silver to the ton and from 20 to 60 per cent. of lead, so-called high-grade "dry" ores, consisting chiefly of kaolin with quartz and garnets, containing from 4 to 300 oz. of silver to the ton and about 3 per cent. of lead, and low-grade dry ores, which resemble the carbonate of lead ore, except that they contain less carbonate of lead and more siliceous gangue; these carry 5 to 40 oz. of silver to the ton. There is evidence, throughout all these oxidised ores, of the action of meteoric waters, in the form of cavities, containing stalactites of psilomelane, limonite and calamine, and it is to the leaching action of these waters that the freedom of the oxidised ores from any notable proportion of zinc must be attributed, for they have no doubt been formed by the oxidation of the sulphide ore met with in depth. The average of a large number of samples of sulphide ore, which consists of an intimate mixture of blende and galena carrying silver, gave :—

Lead	27·4 per cent.
Zinc	20·5 ,,
Silver	21·8 oz. to the ton.

The table on following page [2] shows the results obtained by the Proprietary Company since the commencement of operations :—

1 "The Ore Deposits of the Australian Broken Hill Consols Mine," *Trans. Amer. Inst. Min. Eng.* 1896.

2 *Report of the Directors of the Broken Hill Proprietary Company, Limited, for half-year ending* 30*th November*, 1895.

SCHEDULE.—TOTALS OF REPORTED YIELDS.

For each Half-year, from commencement of the Company to 28th November, 1895.

Half-year ending	Ore treated, gross. (including moisture.)				Concentrates.				Flue Dust.				Ore treated, net. (Including flue dust.)				Bullion obtained.				Fine Silver.	Lead.			
	Tons	cwt.	qr.	lb.	Tons	cwt.	qr.	lb.	Tons	cwt.	qr.	lb.	Tons	cwt.	qr.	lb.	Tons	cwt.	qr.	lb.	Oz.	Tons	cwt.	qr.	lb.
25th Nov., 1886	10,397	0	0	0	—				—				10,397	0	2	0	2,107	11	3	0	871,665	1,990	17	3	0
2nd June, 1887	18,411	0	0	0	—				—				18,410	16	3	0	2,861	12	3	0	835,526	2,836	7	1	0
1st Dec., ,,	30,432	0	0	0	—				—				28,799	18	0	25	6,550	9	2	17	1,267,699	6,511	13	3	11
31st May, 1888	41,349	0	0	0	—				34	18	2	23	39,789	8	3	26	6,823	19	3	5	1,633,737	6,773	19	2	15
30th Nov., ,,	57,286	0	0	0	—				1,440	2	1	9	54,336	0	2	6	9,955	12	3	23	2,290,455	9,885	10	2	23
31st May, 1889	71,055	0	0	0	—				803	12	3	13	68,545	4	2	13	11,499	9	2	18	2,677,686	11,417	10	0	12
30th Nov., ,,	77,017	0	0	0	7,239	8	0	0	1,260	13	3	0	73,424	14	2	20	13,761	0	0	19	3,325,613	13,659	4	0	15
31st May, 1890	85,208	0	0	0	8,739	0	0	0	1,474	7	3	5	81,600	18	2	14	15,516	10	0	7	3,814,486	15,399	14	2	27
30th Nov., ,,	91,923	0	0	0	6,110	0	0	0	1,507	14	1	5	87,819	9	3	22	15,051	12	3	17	3,697,196	14,938	19	0	22
31st May, 1891	134,943	0	0	0	881	0	0	0	1,564	8	1	22	129,233	12	1	0	23,771	9	0	4	4,796,342	23,624	12	1	19
3rd Dec., ,,	131,147	0	0	0	6,155	0	0	0	1,245	5	1	20	123,583	13	2	4	17,299	10	2	1	4,841,650	17,150	15	0	7
2nd June, 1892	157,957	5	0	0	2,982	0	0	0	2,431	19	0	16	148,386	5	2	15	24,088	16	0	22	5,048,454	23,932	5	0	27
1st Dec., ,,	66,339	0	0	0	3,244	0	0	0	1,425	17	3	8	62,568	2	3	20	9,039	18	1	6	2,120,523	8,975	11	1	18
1st June, 1893	208,042	0	0	0	6,779	0	0	0	2,048	3	1	5	196,274	14	2	9	21,860	11	0	10	5,894,962	21,690	0	1	10
30th Nov., ,,	246,520	0	0	0	5,005	0	0	0	2,920	16	1	13	232,623	8	1	14	25,800	0	0	11	6,533,232	25,609	7	3	23
31st May, 1894	272,121	0	0	0	—				2,875	15	1	13	260,154	9	2	15	25,848	5	1	1	7,287,337	25,638	14	3	14
29th Nov., ,,	324,028	0	0	0	766	0	0	0	2,146	11	2	4	311,462	2	1	3	24,144	4	0	7	6,767,056	23,955	12	3	12
30th May, 1895	277,092	0	0	0	3,371	0	0	0	1,902	15	1	9	267,358	17	0	2	19,526	3	0	6	6,233,720	19,358	17	0	13
28th Nov., ,,	211,475	0	0	0	2,477	0	0	0	1,581	15	0	7	205,619	7	0	27	13,830	0	2	13	4,158,551	13,711	10	3	25
Silver obtained from ore treated at foreign reduction works	—				—				—				—				—				180,209	—			
Gross totals	2,512,742	5	0	0	53,748	8	0	0	26,664	17	2	4	2,400,388	6	1	11	289,336	17	3	19	74,276,099	287,061	5	2	13

The total gross amount distributed in dividends amounted to £8,160,000 during these nine and a half years.

Numerous other companies are working on the main lode and on the parallel lodes, the ores being in each case practically of the same class. Thus the British Broken Hill Proprietary Company, Limited, are working the main and the north-eastern lodes and extracting 4,000 to 5,000 tons of ore per annum; in the year ending June 30th, 1895, the amount was 4,795 tons, averaging about 20 per cent. of lead and 50 oz. of silver to the ton. The Consols lode differs, as already stated, from the other vein of the Broken Hill lode system. It is only about 18 inches wide, strikes east and west dipping 24° to the south at the surface, but is nearly vertical in depth; it has been traced for a length of 1,300 feet and to a depth of over 300 feet. It thus cuts across the bedding of the metamorphic rocks in which it occurs; the limits of the ore shoots are within so much of the lode as traverses a series of dykes of amphibolite, the vein pinching whenever it enters the metamorphic rocks. According to Mr. Smith (*loc. cit.*) the diorite carries two separate and parallel cross-veins of blende, pyrites, &c., in quartz, varying from a mere streak to three feet in thickness. Wherever the vein intersects these cross-veins, valuable deposits of silver ore have been found. The analogy between this occurrence and the fahlbands of Kongsberg is too obvious to be overlooked. The ores of the Consols lode are not silver lead like those of the other lodes, but consist of true silver ores, chiefly stromeyerite and discrasite; these silver ores are always associated with cobalt minerals.

Included within the same mining division, the Albert division, there are several other mineral fields of less importance. The Pinnacles Mines lie about nine miles south-west from Broken Hill.[1] There are a series of lodes lying about parallel to the foliation planes of the gneiss which forms the country rock, the veinstuff passing gradually into the country rock without well-defined walls; they are probably therefore bedded veins formed metasomatically, the mineralising solutions having made their way through certain of these foliation planes. The ores are chiefly argentiferous galena and pyrrhotine with very little zinc, the gangue consisting of garnets and quartz; the ore averages 25 oz. of silver to the ton and 12 per cent. of lead. At Thackeringa and other places.

[1] J. B. Jaquet, "Geology of the Broken Hill Lode and Barrier Ranges Mineral Field," *Memoirs of the Geological Survey of New South Wales*, Sydney, 1894, p. 107.

bedded veins carrying ores resembling those of the Broken Hill lodes have been worked. During 1894 work was almost confined to the Broken Hill district. The tctal quantities and values of minerals produced during 1894 and 1895 in this field were as follows :—[1]

	1894.		1895.	
	Weight.	Value.	Weight.	Value.
Gold	4,079 oz.	—	4,650 oz.	£18,600
Silver lead bullion	42,509 tons	£1,543,038	29,684 tons	959,562
Silver lead ore	137,385 ,,	644,896	189,133 ,,	587,255
Silver ingots	511,090 oz.	61,194	472,449 oz.	57,804
Copper ore	80 tons	673	23 tons	112
Copper matte	190 ,,	500	1,004 ,,	21,230
Iron ore	254 ,,	256	—	—
Tin ore	25 ,,	1,172	—	—
Total values		£2,251,729		£1,644,563

The total amount of pure silver in the above may be taken at about twelve million and eight and two-third million ounces respectively.

In addition to the silver obtained from silver and lead ores, native gold is invariably alloyed with that metal, and consequently a very considerable quantity of silver has accompanied the Australian gold through various commercial channels. Although in the aggregate the amount will be somewhat large, the value of this silver is relatively so small that it is not taken into consideration in the estimates of gold produced. The following is the official return of the silver produced in the colony of New South Wales from 1862 to 1895 :—[1]

Table showing Weight and Value of Silver Ores and Silver produced in New South Wales prior to 1869.

Year.	Quantity.	Value.
		£
1862	266 tons ore.	5,320
1863	28 ,,	1,080
1864	13 ,,	130
1865	736 oz. silver.	184
1866	Nil.	—
1867	,,	—
1868	,,	—
Total prior to 1869		6,714

[1] *Annual Reports of the Department of Mines.*

TABLE SHOWING WEIGHT AND VALUE OF SILVER PRODUCED IN NEW SOUTH WALES FROM 1869 TO 1881 INCLUSIVE.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Oz.	£		Oz.	£
To end of 1868	—	6,714	1875	52,553	12,794
1869	753	199	1876	69,179	15,456
1870	13,868	3,801	1877	31,409	6,673
1871	71,311	18,681	1878	60,563	13,291
1872	49,544	12,663	1879	83,164	18,071
1873	66,998	16,278	1880	91,419	21,878
1874	78,027	18,880	1881	57,254	13,026
Totals				726,042	178,405

QUANTITIES AND VALUES OF SILVER, SILVER-LEAD AND ORE EXPORTED FROM (PRODUCED IN) NEW SOUTH WALES FROM 1881 TO THE END OF 1895.[1]

Year.	Silver.		Silver-lead and ore.			Total value.
	Quantity.	Value.	Ore. Quantity.	Metal. Quantity.	Value.	
	Oz.	£	Tons.	Tons.	£	£
Up to 1881	726,779	178,405	192	—	5,025	183,430
1882	38,618	9,024	12	—	360	9,384
1883	77,065	16,488	136	—	2,075	18,563
1884	93,660	19,780	9,168	—	241,940	261,720
1885	794,174	158,187	2,096	190	107,626	266,813
1886	1,015,433	197,544	4,802	—	294,485	492,029
1887	177,308	32,458	12,529	—	541,952	574,410
1888	375,064	66,668	11,739	18,103	1,075,737	1,142,405
1889	416,895	72,001	46,965	34,580	1,899,197	1,971,198
1890	496,553	95,410	89,720	41,320	2,667,144	2,762,554
1891	729,590	134,850	92,384	55,396	3,484,739	3,619,589
1892	350,662	56,884	87,505	45,850	2,420,952	2,477,836
1893	531,972	78,131	155,859	58,401	2,953,589	3,031,720
1894	846,822	94,150	137,813	42,513	2,195,339	2,289,489
1895	550,142	81,858	191,193	29,687	1,560,813	1,642,671
Totals	7,220,737	1,292,838	841,113	326,040	19,450,973	20,743,811

COPPER.—Copper ores have for many years figured among the productions of New South Wales, but for some time copper mining was conducted upon a very limited scale. During the earlier

[1] *Annual Report of the Department of Mines for* 1895, p. 54.

periods of mining activity, the cost of transporting bulky ores from the interior of the colony to the sea coast for shipment placed the copper miner at considerable disadvantage as compared with the gold digger. Washing for gold was, therefore, generally preferred to mining for an ore the value of which could only be realised after a large expenditure of time and money. In order to obviate, as far as possible, this difficulty, copper miners, at a comparatively early date, commenced the erection of furnaces for the production of regulus, and the process was subsequently extended to the manufacture of fine copper.

The first mention of copper ores in the statistics of the colony appears to occur in 1858, in which year 58 tons, of the value of £1,400, are stated to have been raised. The first smelting furnaces appear to have been erected about the year 1863, since which date the production of copper ores and copper has steadily and somewhat rapidly increased. Unfortunately, however, the official records of the colony supply more information with regard to the annual production of copper than with respect to the mode of occurrence of its ores.

The Great Cobar Copper Mine, which was for a good many years the most important copper mine of New South Wales, is situated almost in the centre of the vast plain which lies between the Darling, the Bogan, and the Lachlan rivers, the country for many miles around being entirely waterless. The rocks consist of Silurian slates, which within the limits of the property are supposed to be traversed by several lodes. Operations have hitherto been confined to the most western one only, upon which four shafts have been sunk. Barton's Shaft had, in 1880, been sunk to a depth of 54 fathoms, and in that year the inspector of mines reported the lode at the bottom to be 46 feet in width and to consist entirely of solid sulphides. At the bottom of Becker's Shaft, which had been sunk to the same depth as the other, a solid course of ore, averaging 26 feet in width, extended between the two shafts, a distance of about 100 fathoms. From Becker's Shaft on the north, to Renwick's Shaft on the south, the lode had been worked for a length of about 193 fathoms, and consisted of a mixture of carbonates, oxides, and gray copper ores, with oxide of iron, varying in thickness from three to 100 feet.

The rapid development of this mine is shown by the following statistical statement.[1]

[1] *Annual Report of the Department of Mines for* 1880, Sydney, 1881, p. 217.

Year.	Ore smelted	Copper produced.
	Tons.	Tons.
1876	1,458	174
1877	4,880	523
1878	8,389	1,457
1879	12,615	1,891
1880	20,566	2,600
1881	21,552	2,568
1882	11,702	1,805
Totals since the mine started, 1876	81,162	11,018

The mine was closed down in 1889, up to which date it had produced about 23,000 tons of metallic copper, but it was restarted in 1894, in which year the production was 13,460 tons of ore, yielding 665 tons of smelted copper, valued at £26,600. In 1895[1] there were 37,845 tons of ore raised, producing 1,703 tons of smelted copper, worth £68,120.

The Nimmagee Copper Mine, about sixty-five miles south of Cobar, is one of the most important of the more recent undertakings. Four shafts had, in 1881, been sunk on the property, the deepest of which had reached a depth of 27 fathoms from the surface. In this shaft the lode was 6 feet in width, and entirely composed of good ore suitable for the furnace. An end, going north, had been driven above 60 fathoms through a lode composed of quartz, gossan, and gray copper ore. Another shaft had been sunk for a depth of 12 fathoms through a lode composed of quartz, gossan, iron pyrites, and yellow copper ore. About 500 tons of 16 per cent. ore was lying on the surface ready for the smelting furnaces in 1881. In 1894 this Company raised 1,688 tons of ore, yielding 148½ tons of smelted copper, valued at £5,490, and in 1895 the production was 5,845 tons of ore, yielding 485 tons of smelted copper, worth £21,825. Another important producer is the Burraga Copper Mine, near Burraga, which produced 622 tons of metallic copper in 1894. In 1895 the lode was lost, but was picked up again; the output for the latter year was 3,311 tons of ore, producing 331 tons of copper, worth £14,895.

The New Cobar Copper Mine, which is only about eight miles south of Great Cobar, has also been extensively worked. The approximate area of the copper-bearing region of New South Wales has been estimated at about 6,700 square miles.

[1] *Annual Report of the Department of Mines for* 1895, p. 61.

The following table[1] shows the quantity and value of copper, copper ore, &c., exported from the colony from 1858 to 1895 :—

TABLE SHOWING THE QUANTITY AND VALUE OF COPPER, COPPER ORE AND REGULUS, THE PRODUCE OF THE COLONY, EXPORTED FROM NEW SOUTH WALES, FROM 1858 TO 1895 INCLUSIVE.

Year.	Ingots.		Ore and Regulus.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Tons cwt.	£	Tons cwt.	£	Tons cwt.	£
1858	—	—	58 0	1,400	58 0	1,400
1859	30 0	578	—	—	30 0	578
1860	—	—	43 0	1,535	43 0	1,535
1861	—	—	144 0	3,390	144 0	3,390
1862	—	—	213 0	5,742	213 0	5,742
1863	23 0	1,680	114 0	420	137 0	2,100
1864	54 0	5,230	—	—	54 0	5,230
1865	247 0	15,820	22 0	545	269 0	16,365
1866	255 0	18,905	23 0	1,885	278 0	20,790
1867	393 0	30,189	0 2	5	393 2	30,194
1868	644 0	23,297	172 0	4,000	816 0	27,297
1869	1,980 0	74,605	104 0	2,070	2,084 0	76,675
1870	994 0	65,671	6 0	60	1,000 0	65,731
1871	1,350 0	87,579	94 0	1,297	1,444 0	88,876
1872	1,035 0	92,736	417 0	13,152	1,452 0	105,888
1873	2,795 0	237,412	51 0	1,690	2,846 0	239,102
1874	3,638 0	311,519	522 0	13,621	4,160 0	325,140
1875	3,520 0	297,334	157 0	4,356	3,677 0	301,690
1876	3,106 0	243,142	169 0	6,836	3,275 0	249,978
1877	4,153 0	307,181	360 0	17,045	4,513 0	324,226
1878	4,983 0	337,409	236 0	7,749	5,219 0	345,158
1879	4,106 15	256,437	36 7	915	4,143 2	257,352
1880	5,262 10	359,260	131 18½	4,799	5,394 8½	364,059
1881	5,361 0	350,087	132 16	4,975	5,493 16	355,062
1882	4,865 3	321,887	93 1	2,840	4,958 4	324,727
1883	8,872 17	574,497	84 10	2,704	8,957 7	577,201
1884	7,286 6	415,601	18 18	578	7,305 4	416,179
1885	5,745 5	264,905	0 15	15	5,746 0	264,920
1886	3,968 18	166,429	57 18	1,236	4,026 8	167,665
1887	4,463 19	195,752	299 8	3,350	4,763 7	199,102
1888	3,786 1	272,110	113 6	2,924	3,899 7	275,034
1889	3,983 16	203,319	198 4	3,322	4,182 0	206,641
1890	3,165 9	163,537	580 9	9,774	3,755 18	173,311
1891	3,860 3	191,878	665 8	13,215	4,525 11	205,093
1892	3,535 0	160,473	1,299 4	27,233	4,834 4	187,706
1893	1,051 0	44,235	1,016 0	14,191	2,067 0	58,426
1894	1,556 11	61,034	580 6	12,447	2,136 17	73,481
1895	2,793 3	119,300	1,058 0	21,585	3,851 3	140,885
Totals	102,863 16	6,271,028	9,281 0½	212,901	112,144 16½	6,483,929

TIN.—The most important tin-fields of New South Wales are those situated near the Queensland boundary, but tin ore also

[1] *Annual Report of the Department of Mines for* 1895, p. 62.

occurs, although in less abundance, in some of the more southern portions of the colony. Attention was first called to the probable occurrence of considerable quantities of this mineral by the Rev. W. B. Clarke, to whose investigations relative to the geology and mineral resources of Australia reference has already been made. In a report to the Colonial Secretary, dated May 7th, 1853, Mr. Clarke expressed his opinion strongly with regard to the probable value of the stanniferous deposits of the New England district, but no practical notice was, at the time, taken of his observations. Washing for tin ore was first actively commenced in New South Wales in 1872, and the New England district quickly became famous for its rich deposits of that mineral. Cassiterite was first recognised among the black sands of the Victorian gold-fields in March 1853, but although the occurrence of tin in that colony is comparatively limited, it was not, as in New South Wales, entirely overlooked. Tin ores from Australia were imported into England long previous to 1872, but they appear to have come exclusively from Victoria.

The tin deposits of Australia are not confined to the beds or banks of modern water-courses, but often extend high up their sides, thus indicating that extensive erosion has taken place subsequently to their deposition. Like gold, tin ore is also found in deep leads, which are sometimes covered by flows of basalt, and many of which are regarded as of Miocene age. Granites appear to be the ultimate source of Australian tin ore, and on high ground unworn crystals of cassiterite are occasionally found as a residuary deposit resting on the surface of decomposed granite. The granites have been stated to be of Devonian age, and the tin veins which traverse them do not, as in Cornwall, exhibit an approximate uniformity of strike. According to Mr. T. W. Edgeworth David,[1] who published a very complete monograph on the Vegetable Creek district in 1887, the stanniferous granites cover an area of 297 square miles, and are probably of Permian age. They form well-marked bosses, piercing dark-coloured clay slates and shales, and are associated with eruptive eurites and porphyries. The area of the New South Wales tin-fields was estimated at about 8,500 square miles, and 2,200 persons were said to be employed in tin mining in 1880, the figures for 1895 not being very different.

Tin streams began to be profitably worked early in the year

[1] "Geology of the Vegetable Creek Tin-Mining Field," *Geol. Survey of N.S.W.* 1887, p. 23.

1872, some of the first deposits of ore having been discovered in the neighbourhood of Bendemeer; and almost simultaneously a large extent of land was taken up for tin mining in the neighbourhood of Watson's Creek, twenty miles west of the last-named locality. Then there came information of tin ore having been found near the Queensland border, and streamworks, some of which proved to be very rich, were opened around Stanthorpe. After the Stanthorpe mines, came discoveries in the vicinity of Dundee, and about the same time the deposits of Cope's Creek, near Inverell, were brought to light. Discoveries at Vegetable Creek quickly followed these, where, as well as at Inverell, the workings were carried out upon a large scale and with very profitable results. Some of these original shallow deposits have been long since worked out, but a large number of deep leads, then entirely unknown, are now in active operation. An enormous quantity of tin ore has been taken from the mines in Vegetable Creek, which may be regarded as the centre of the richest discoveries of that mineral in the colony. From 1872 to December 31, 1880, the total yield of tin (black tin?) from workings in the Vegetable Creek district, is stated to have amounted to 20,988 tons.[1]

The deep lead worked by Wesley Brothers at Vegetable Creek is one of the richest discoveries of tin-bearing drift ever made in the district, even eclipsing the celebrated deposit worked by the Vegetable Creek Tin Mining Company. After sinking through 90 feet of basalt, 60 feet of which was exceedingly hard, together with various layers of pipeclay, their perseverance was rewarded by the discovery of a bed of rich wash-dirt. When they had followed the rock on which they bottomed, which was dipping rapidly, for a depth of about twenty feet, they came upon the wash, consisting of ten feet of fine sandy drift, with a fair amount of stream tin. Below this was a layer of coarse gravelly drift, exactly like that seen in the bed of an ordinary river, which was wonderfully rich. In the year 1879 they were unable to reach the bed-rock on account of the large amount of water, but a new shaft was being sunk with a view of reaching the bottom of the deposit. Fig. 113 represents a section of Wesley Brothers' old shaft looking west.

In 1880 the width of the lead had been proved to be 170 feet, and workings had extended upon its direction for a distance of 340 feet. The wash was found to be exceedingly rich, and in

[1] C. Lyne, *The Industries of New South Wales*, p. 190.

many places was black with tin oxide; but, being composed of gravel and very fine sand, the whole of the workings had to be close lathed and double planked. The yield of black tin, which

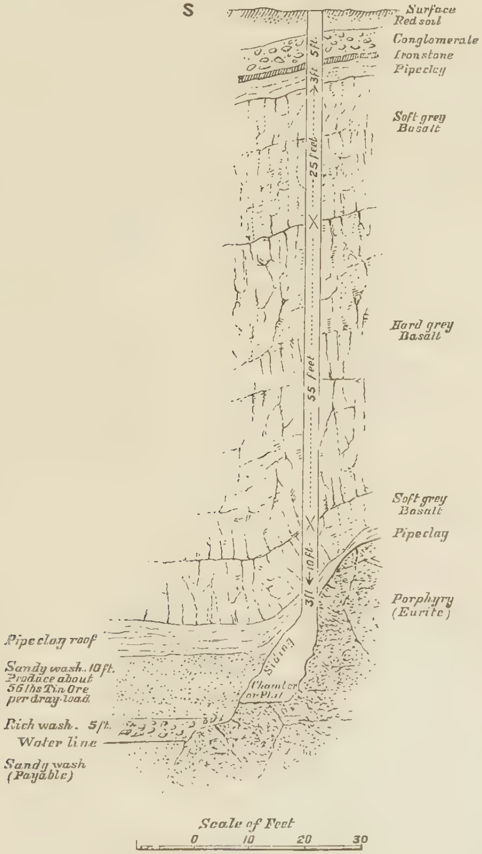


FIG. 113.—Wesley Brothers' old shaft; vertical section.

was 286 tons for the year, would have been considerably larger had there not been a scarcity of water during the earlier months.

The great event of the year 1880 appears to have been the striking of remarkably rich wash-dirt at Rose Valley, near Vegetable Creek, where, after sinking through sixty feet of soft gray basalt and twenty of variously coloured pipeclays, exceedingly rich tin-bearing wash-dirt, which varied in thickness from 2 to 8½ feet, was found. The width of this lead was proved to be about 100 feet, and drifts were extended for a distance of 300 feet upon its course. From these workings 553½ tons of tin ore were obtained during the course of nine months.

Vegetable Creek presents examples of several distinct forms of tin deposits.[1] Alluvial tin is found both in the deep leads of the early Tertiary period, and in shallow leads of recent and Pleistocene age. Lode tin occurs in fissure veins, in gash veins, in joints of the granite, in impregnations and in stock works.

The shallow leads had up to 1886 yielded some 15,000 tons of ore from a length of about 5 miles and an area of about 150 acres. The depth varies from 1 to 15 feet with an average of 7 feet, and the thickness of the pay gravel from 2 to 7 feet with an average of 2½ feet. These figures work out to a richness of 2½ per cent. or ½ cwt. to the cubic yard of pay gravel, or about 20 lb. to the cubic yard of excavation of the entire deposit.

The deep lead has been found to be very variable; its thickness is from 1 to 13 feet with an average of about 6 feet, and an average width of some 80 feet. In spots it has yielded 100 lb. of tin ore to the cubic yard of pay gravel. In some places an upper lead has been found overlying the main basalt, and passing under a sheet of more recent lava. Up to 1886 the deep leads had produced 6,000 tons of ore from a length of close on 2½ miles.

Numerous tin lodes were known to exist in various localities in New South Wales, but no vein mining of any considerable extent had been undertaken before 1882. Near Cope's Creek in the granitic country, thirty-five miles north-west of Armidale, a number of large stones of solid tin ore were at one time obtained from the outcrop of a lode. One of these lumps is said to have weighed 57 lbs., and to have yielded by assay 76 per cent. of metallic tin. The tin ore at the Bolitho Mine runs in irregular branches through a nearly vertical felspathic dyke. These veins sometimes unite so as to form an almost solid mass of ore, and then again dwindle and disappear. Several large blocks of vein-stone raised from this place, one of which weighed nearly a ton, are stated to have mainly consisted of tin ore. At the Bismarck Mine, south of Cope's Creek, a dyke of felstone has been discovered containing tin veins. The tinstone is here associated with quartz in veins varying from a mere string to branches three inches in width, which traverse the dyke in all directions. The ore usually occurs in the form of crystals lining the sides of fissures, the central portions of which are filled with quartz. A vein of nearly pure cassiterite, four

[1] T. W. E. David, *op. cit.*

inches in width, associated with clay and fluor spar, is said to have been opened at the Boundary Tin Mine.

Several tin lodes occur near Tingha, some of which are stated to have produced solid masses of tin ore several inches in thickness; but with the exception of two, one worked by an Englishman and the other by Chinamen, they were all deserted in 1880. Tin lodes are also known in numerous other districts, generally in granite, at times in greisen and in eurite [1]; they are most typically developed in the Vegetable Creek district, where they are now largely worked.

Lode mining early became an important factor in the tin output at Vegetable Creek. Thus in 1886 [2] and 1895 the yield from each class of working was follows:—

	1886. Tons	1886. cwt.	1895. Tons.
Lode workings	169	13	286
Shallow lead workings	761	1	499
Deep lead workings	962	8	115
Totals	1893	2	900

The former proportion was, however, maintained practically unchanged for some years till quite recently.

The most important form of lode tin deposit is in true fissure veins and in gash veins or joint veins, which closely resemble the former; they are either right running veins, that is, parallel to the principal system of joints in the granite, or marginal, that is, parallel with the junction of the granite and the clay state. The ore shows a marked tendency to form shoots, whose average length is about 100 feet, depth about 6 feet, and width 1½ feet; the average dip is about 26°, mostly in a north-easterly direction. The average strike of the right-running veins is 39° 15′ east of north and west of south, the angle ranging between 24° and 70° east of north. The average dip is 77°; 33 veins dip north-westerly, 10 south-easterly, and 3 are vertical. The gangue is mostly quartz, more rarely chlorite or felspar, whilst all the minerals associated with tinstones in other parts of the world also occur here. The country rock is mostly granite; 76 veins are enclosed in granite, 8 in quartz porphyry and eurite, 3 each in porphyroid and claystone.

[1] A. Liversidge, *The Minerals of New South Wales*, 1888, p. 78.

[2] T. W. E. David, *op. cit.*

The most favourable country is a moderately hard open-grained Tertiary granite, with rather large greenish felspar crystals. The greatest length over which any vein has been proved to be tin-bearing is one mile (Butler's vein). The greatest width is about 4 feet (Ottery's vein), the average width being about 1 foot 6 inches. The maximum depth in 1886 was 200 feet. The richness of the veinstone varies within very wide limits, but seems to average about 3½ per cent. Up to 1886 lode mining had yielded 1,570 tons of ore.

This division, known as the Emmaville division, was in 1895[1] the leading tin-producing district of New South Wales. The 900 tons here produced, distributed as shown on the previous page, were valued at £29,700, and were the product of the work of 350 Europeans and 260 Chinamen. The low returns as compared with the previous year are stated to be due to long-continued drought, which greatly impeded dressing operations. The principal lode mining was still being carried on at the Ottery Tin Mine on Trent Hill. The lode here is said to have varied from 3 to 25 feet in width, carrying about 3 per cent. of tin, and this mine is said to have produced 181 tons of dressed ore, or about two-thirds of the entire output of lode tin from this division. Not much work was being done at Butler's Mine during the year.

It is noticeable that here, as elsewhere, the tin-bearing portion of the granite is practically confined to a belt that forms the outer crust of the boss; it ceases to be tin-bearing at a distance of about 1½ miles from its junction with the clay slate. Some of these veins run within fairly well-defined walls; in other cases impregnations extend along both walls of a narrow median fissure, the granite on either side getting gradually poorer in tin. In yet other instances, many minute veinlets of tinstone and quartz traverse quartz porphyry or felsite, as at Strathbogie North, forming a true stock-work. Taken altogether this district presents many analogies with the occurrences at Zinnwald and other places in the Erzgebirge.

Native tin has been discovered in the sands of the Aberfoil river in minute crystalline grains rarely exceeding 1 millimetre in diameter.[2]

The following table[3] shows the quantity and value of tin and tin ore exported from the opening of the tin-fields in 1872 to the end of 1895:—

[1] *Annual Report of the Department of Mines for* 1895, p. 59.
[2] A. Liversidge, *The Minerals of New South Wales*, 1888, p. 76
[3] *Annual Report of the Department of Mines for* 1895, p. 60.

TABLE SHOWING THE QUANTITY AND VALUE OF TIN AND TIN ORE, THE PRODUCE OF THE COLONY, EXPORTED FROM NEW SOUTH WALES TO END OF 1895.

Year.	Ingots.		Ore.		Total.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Tons.	£	Tons.	£	Tons.	£
1872	47	6,482	849	41,337	896	47,819
1873	911	107,795	3,660	226,641	4,571	334,436
1874	4,101	366,189	2,118	118,133	6,219	484,322
1875	6,058	475,168	2,022	86,143	8,080	561,311
1876	5,449	379,318	1,509	60,320	6,958	439,638
1877	7,230	477,952	824	30,588	8,054	508,540
1878	6,085	362,072	1,125	33,750	7,210	395,822
1879	5,107	343,075	814	29,274	5,921	372,349
1880	5,476	440,615	682	30,722	6,159	471,337
1881	7,591	686,511	609	37,492	8,200	724,003
1882	8,059	800,571	611	32,890	8,670	833,461
1883	8,680	802,867	445	21,685	9,125	824,552
1884	6,316	506,726	350	14,861	6,666	521,587
1885	4,658	390,458	535	25,168	5,193	415,626
1886	4,641	449,303	327	18,350	4,968	467,653
1887	4,669	509,009	292	16,411	4,961	525,420
1888	4,562	569,182	247	13,314	4,810	582,496
1889	4,409	403,111	242	12,060	4,651	415,171
1890	3,410	317,117	259	12,724	3,669	329,841
1891	2,941	261,769	203	9,643	3,144	271,412
1892	3,253	301,541	239	12,573	3,492	314,114
1893	2,637	223,139	148	6,604	2,785	229,743
1894	2,611	179,445	190	7,752	2,802	187,197
1895	2,200	136,080	77	2,543	2,277	138,623
Totals	111,100	9,495,495	18,378	900,978	129,776	10,396,473

IRON.—Important deposits of iron ore are found in close proximity to coal and limestone in various parts of the colony. The ore found at Mittagong, in the southern district, contains 65 per cent. of iron. The iron ore at Wallerawang, distant 105 miles from Sydney, consists of magnetite and brown hæmatite, in addition to which there are beds of so-called clay bands interstratified in the Coal-measures. These clay bands are not impure carbonates, but brown hæmatites containing about 50 per cent. of iron. Bands of highly ferruginous garnets accompany the veins of magnetite. Deposits of red and brown hæmatite are also known in numerous other localities, although they are practically unworked.

The Eskbank Iron Company, who have established works at Lithgow, 95 miles from Sydney, are the largest manufacturers of iron in the colony. These works are connected by a tramway with the Great Western Railway. The ores treated consisted of a clay band stone averaging 40 per cent. of iron, a brown hæmatite yielding 50 per cent. of metal, and a siliceous ore containing a somewhat low percentage of iron. The first, which crops out at the surface, varies from six to fifteen inches in thickness, the second forms a bed two feet thick, while the thickness of the third is four feet. A ten-feet seam of splint coal crops out upon this property, as does also a seam of refractory clay, from which fire-bricks are manufactured. The make during the year 1880 amounted to 1,200 tons of pig-iron and 800 tons of bars and rails. In 1894 no iron was smelted in the colony, the Eskbank Works producing 2,368 tons of manufactured iron from scrap. A little iron ore is mined for flux in the Broken Hill district.

Lead.—The only lead mines worked are those in which argentiferous lead ores are raised, and these have already been described under the head of silver. Native lead[1] seems to have been found in one or two places. It occurs associated with serpentine on spurs of the Curangora.

Antimony.—Stibnite occurs in various parts of New South Wales, and during the year 1880 some discoveries of that mineral were reported to have been made. At a mine opened near Armidale the vein varies in width from 10 to 15 inches, and the ore is stated to yield 50 per cent. of antimony, and 1 oz. 2 dwt. of gold per ton. The ore from another mine is said to yield 66 per cent. of antimony. Antimony lodes have been discovered at Hargrave's Falls and in the neighbourhood of Aberfoil. Some lodes in the Macleay district have been worked, while in the Bathurst district, pure blocks of stibnite occur, but without any defined lode. The antimonial ores on the Munga Creek, four miles above its junction with the Macleay River, occur in a quartzose matrix in lodes having a general strike between north and north-east; the Victoria reef is, however, an exception in this respect. Antimony and antimony ores weighing 99 tons 19 cwts., and having a value of £1,652, were exported during the year 1880. In 1894[2] the bulk of the antimony produced came from the Hillgrove district, which raised 632 tons; the total amount produced in that year was 1,230 tons, valued at £18,744. The total production of the colony since 1871, when it seems to have been first mined, was 9,820 tons, valued at £174,314 up to the end of 1894. The low price ruling greatly reduced the output in 1895, in which year the Hillgrove district raised about 400 tons, valued at £4,000.

[1] A. Liversidge, *op. cit.* p. 62.

[2] *Annual Report of the Department of Mines for* 1894, p. 55.

Bismuth.—This metal occurs in a vein 8 inches wide at Silent Grove, and also in the Vegetable Creek district. It is likewise worked at the Elsmore Mine on the McIntyre River, near Inverell, and in the vicinity of Glen Innes. Although bismuth has long been known to exist in the latter region, mining for this metal, as an industry, was not commenced until 1880, during which year 4½ tons of ore were exported from the Kingsgate Mine, eighteen miles east of Glen Innes. The lodes in which the metal is found vary from 6 to 8 feet in width, and have an east and west bearing. The country rock is granite and the veinstone quartz, from which masses of native bismuth, weighing from 1 to 2 lb., are sometimes obtained. In 1894 spasmodic work was still being carried on in the Glen Innes district, 9 tons of mineral, valued at £480, having been obtained, and only 2½ tons in 1895.

Platinum.—A little platinum is obtained in several districts in the course of gold washing. The chief locality is the Fifield gold-field,[1] where about 1,000 ounces, valued at 23s. per oz., were obtained in 1894. It has also been found in the sands of the Aberfoil river, and in various other places, amongst them being the sea beach between the Richmond and Clarence rivers.

A nugget weighing 268 grains is said to have been found in the bed of Wiseman's Creek near Oberon. Near Broken Hill platinum is found in ironstone, ferruginous claystone and decomposed gneiss, but these deposits have not been as yet worked commercially with success, nor is the mode of occurrence in them of the platinum known with any exactitude.

At Fifield alluvial platinum occurs with alluvial gold in the gravel of an ancient watercourse; the wash-dirt has yielded from 5 to 12 dwt. of crude platinum (containing about 75 per cent. of metal) and from 1 to 3 dwt. of gold to the load, the total money value of the dirt thus varying from 9s. to 37s. per load. M. Jaquet considers this lead as having been produced by the natural reconcentration of a bed of conglomerate of probably Tertiary age. Up to the time of writing (the beginning of 1896) this small lead had produced some 1,200 ounces of crude platinum.

Chromium.—Chrome iron ore has been found in a great many localities associated, as is always the case, with serpentine or serpentinous rocks. It was not, however, worked commercially until 1894, when several large deposits in the Gundagai district

[1] J. B. Jaquet, "The Occurrence of Platinum in New South Wales," *Records Geol. Survey of N.S.W.* v. 1896, pt. i. p. 33.

were opened up, and 3,034 tons, valued at £12,336, were produced; in 1895 the output was 5,500 tons, valued at about £20,000.

MERCURY.—Cinnabar has been found in several localities. Mr. J. E. Carne [1] reports its occurrence close to the Clarence River near Lionsville, where it is found impregnating dykes of felsite and hornblendic granite; serpentine is largely developed in the immediate neighbourhood, and the deposits have nowhere been traced into the sedimentary rock of the district, which consists of altered Devonian slate. The cinnabar seems to have been brought in solution through fissures in the igneous rock, and to have been partly deposited in these, and partly by metasomasis in the igneous rock itself. Too little work has yet been done to be able to form any idea of the importance of this deposit.

OTHER METALS.—Amongst these may be mentioned ores of cobalt, nickel, manganese, and tungsten, all of which are known to exist, and are sometimes worked on an insignificant scale.

The following table [2] shows the production of metalliferous minerals in the colony during the year 1895:—

QUANTITIES AND VALUES OF METALLIFEROUS MINERALS OR METALS PRODUCED IN NEW SOUTH WALES DURING THE YEAR 1895.

Mineral or Metal.	Weight.	Value.
		£
Gold	360,165 oz.	1,315,929
Silver	550,142 ,,	81,858
Tin	2,276 tons	138,623
Copper	3,851 ,,	140,885
Iron (from scrap)	2,403 ,,	15,620
Antimony	9,479 ,,	7,251
Silver-lead and ores . .	219,881 ,,	1,560,813
Manganese	3 ,,	10
Oxide of iron and pig-iron	152 ,,	348
Chrome	4,229 ,,	13,048
Pig lead	20 ,,	197

QUEENSLAND.

This, the most recently organised of the Australian possessions, was separated from New South Wales in 1859. Its most important metalliferous productions are gold and tinstone, but, in

[1] "Discovery of Mercury near Lionsville," *Min. Jour.* 1896, p. 519. *Annual Report of the Department of Mines for* 1895, p. 141.

[2] *Annual Report of the Department of Mines for* 1895, p. 14.

addition to these, Queensland has, in the aggregate, yielded considerable quantities of copper ore.

Gold.—The gold-fields of the colony, which are grouped in three divisions, namely, the Northern, the Central, and the Southern, exceed twenty in number, but, with few exceptions, exhibit, generally speaking, no peculiarities differing from those which have been already described under the heads of Victoria and New South Wales. Mr. Daintree has called attention to the fact that, although a large area of Devonian rocks exists in Queensland, and numbers of the gold-fields of the colony are situated in Devonian areas, payable gold is under such circumstances only found where the rocks have been penetrated by eruptive dykes which mostly consist of pyritous diorites. On the Broken river and its tributaries, an area having a breadth of thirty miles with a length of sixty miles is occupied with a persistent outcrop of Devonian strata, in which gold has in no case been discovered in remunerative quantities except in a small gully leading from a ridge where a trap dyke has penetrated the Palæozoic rocks. Various districts, however, where Devonian rocks prevail have at different times been centres of gold-mining enterprise, but, as far as is yet known, the country has, in every case, been traversed by dykes of diorite, diabase or porphyrite. Tufaceous representatives of each of these rocks are sometimes also found interstratified with the upper portion of the same formation, and occasionally also throughout the other beds.

At Gympie, one of the richest quartz-mining districts in the colony, the auriferous area is confined either to veins traversing a crystalline diorite, or within a certain limit of its boundary marked by the presence of fossiliferous diabase tuffs.[1]

At one of the diggings near Peak Downs, water-worn gold occurs in a Carboniferous conglomerate containing *Glossopteris*, resting upon an underlying conformable shale abounding in the same fossil. Mr. Daintree was of opinion that the only reason that water-worn gold has not been more frequently found under similar conditions, is explained by the fact that marine and lacustrine deposits, such as the Carboniferous as well as all the Mesozoic and older Cainozoic strata of the continent, are chiefly built up of sediments which have not been derived from the rocks on which they rest. Only beaches or locally filled fjords of Carboniferous or Mesozoic sea-coast, where auriferous reefs have cropped out and

[1] R. Daintree, "Notes on the Geology of the Colony of Queensland," *Quart. Jour. Geol. Soc.* xxviii. 1872, p. 292.

have had a chance of extensive abrasion, would, he considered, be likely to contain drifted gold.[1]

A large proportion of the gold obtained from Queensland was formerly derived from shallow alluvial workings, some of which are mere washings of the gravels found in river-beds, which are collected from holes and crannies on the surface of the bed-rock. Although a great volcanic outburst, which is regarded as being contemporaneous with the upper volcanic series of Victoria, has overspread enormous areas with basaltic lavas, the working of deep leads below such flows is not extensively prosecuted. Quartz mining is, however, carried on with considerable activity, and the quartz treated is markedly richer than that of Victoria.

In the year 1880 the average yield of the 116,418 tons of auriferous quartz treated amounted to 1 oz. 11 dwt. 12 gr. of gold per ton; the aggregate area of the gold-fields was estimated at 15,725 square miles; and 1,578 distinct quartz lodes had been proved to be auriferous. In 1894 there were crushed 539,886 tons of quartz producing 653,573 oz. of gold, being at the rate of 1 oz. 4 dwt. 5 gr. per ton. Many of the quartz veins when enclosed in sedimentary rocks traverse the planes of bedding at considerable angles, and are, therefore, entitled to be regarded as true veins.

From a report on the mineral resources of the district between the Charters Towers gold-fields and the coast, published in 1879,[2] we learn that gold in small quantities has been found in the gravel of the rivers on the coast side of the range. Areas occupied by recent alluvial deposits are met with at Brennan's Creek and Mossman's Creek, and another extends for some distance along Sandy Creek. Some narrow strips of alluvium on creeks to the south of Charters Towers have yielded considerable quantities of gold, but the narrow alluvial flats on many of the small streams have been almost completely worked out. Some of the tributaries of the Little Star river, more especially that known as Dry or Scrubby Creek, have for many years attracted a few miners, whose desultory labours have been on the whole fairly rewarded. The drift of the Little Red Bluff and the deep lead in connection with it have been repeatedly tried for gold, but with very indifferent success, although the number of shafts sunk in the basalt

[1] "Note on certain Modes of Occurrence of Gold in Australia," *Quart. Jour. Geol. Soc.* xxxiv. 1878, p. 431.

[2] Robert L. Jack, *Report on the Geology and Mineral Resources of the District between Charters Towers Gold-fields and the Coast*, Brisbane, 1879.

sufficiently attests the earnestness with which the work was formerly carried on.

From an examination of the shafts which remained open at the time of his visit, Mr. Jack arrived at the conclusion that but few of them had reached the true bottom. The deep lead to the south-east of Millchester employed the labour of a considerable number of diggers in the year 1872, when a good many made considerable profits. Mr. Jack considers that in this district, generally, it would, in the first instance, be prudent to confine operations to leads in the vicinity of known auriferous reefs; and, for the benefit of intending explorers, quotes Daintree's observation, that it is doubtful if any marine or extensive lacustrine beds, except on their shingle margins, have produced or are ever likely to produce remunerative workings of free gold, for the simple reason that the majority of the sediments of which they are composed are derived from formations the greater part of which were non-auriferous.

Over the whole of the Pre-Devonian metamorphic area, quartz reefs are numerous and the soil is strewn with quartz fragments; from which it is probable that some of the gold may have found its way into the various streams. Numerous dykes of diorite occur throughout the district, and copper and tin ores in considerable quantities have been obtained from the district north of the Burdekin.

The rich gold-field of Charters Towers occupies the western edge of an area of ordinary and syenitic granite, bordering on the little altered slates and grits of the Sandy Creek district. It is only when the reefs of this district are laid down upon a map that any idea can be formed of their general mode of arrangement. They are then found to diverge like rays, from a common centre to which they do not extend, and as there is a break of some 35° in the circle, which commences about 10° east of north, a sort of horseshoe-shaped figure is the result. The lodes thus radially disposed, when seen from near the point towards which they converge, dip in the eastern half of the circle, for the most part to the left, while in the other half their inclination is usually to the right of the observer.

A large proportion of the reefs in the Charters Towers district are enclosed in granite, but they also sometimes occur in porphyry. The veinstone is principally quartz, containing iron pyrites and pyrrhotine, both of which are auriferous, but more particularly the latter; pyrites containing gold is also present in the clay selvages of some of the veins, but the amount is usually not sufficient to leave a profit on the process of extraction. As long ago as the year 1879 some of the quartz mines in this district had already attained a depth exceeding eighty fathoms.

In the year 1894 there were 2,115 men[1] at work in 89 mines in this field; they raised 224,924 tons of quartz which yielded 241,676 ounces of gold. The following table shows the returns of the principal mines:—

Name of mine.	Men employed.	Stone raised.	Gold got.	Dividends paid.
	Number.	Tons.	Oz.	£
Mills Day Dawn United	290	48,240	56,101	101,250
Brilliant	200	32,725	33,347	43,166
Brilliant Block	130	22,640	23,073	36,250
Brilliant and St. George	80	10,656	17,599	33,000
Victoria	76	7,666	13,245	21,600
New Queen	110	7,759	10,446	7,972
Brilliant Central	51	6,808	9,810	11,250
Kelly's Queen Block	40	3,862	8,090	15,800

Deep mining is the rule on this field, there being many shafts over 1,000 feet in depth; the deepest in 1894 were those of the New Brilliant Extended, 2,027 feet (vertical), Day Dawn Block and Wyndham, 2,984 feet (underlie), Mosman 1,576 feet (vertical), and Victoria 1,502 feet (vertical). The amount of gold yielded by this whole gold-field was 251,042 ounces from 231,687 tons of stone. In 1895[2] it was 251,577 ounces from 249,520 tons of stone.

The gold-field next in importance is that of Rockhampton, which produced 123,489 ounces of gold from 78,121 tons of stone in 1894, as a result of the labours of 1,350 miners. Although there are numerous small mines and a good deal of alluvial is worked, this is emphatically a one-mine gold-field. Out of the above totals, the famous Mount Morgan Mine raised 75,798 tons of stone, got 109,668 ounces of gold, and employed about 1,000 men, whilst no one other mine produced 500 ounces.

The Mount Morgan Mine is in many respects one of the most wonderful gold mines of the world. As shown by a very complete series of plans issued with the report of the directors in 1894, it consists of a low hill some 400 feet in height, which has been worked open-cast down to a depth of 158 feet below the summit, the area of the open-cast in that year being about 700 feet by 300 feet. The upper part of the deposit consisted chiefly of a siliceous

[1] *Annual Report of the Under-Secretary for Mines for* 1894, p. 39.

[2] *General Report on the Mining Industry of Queensland for* 1895, p 10.

hæmatite, at times showing coarse visible gold, but more often carrying it in a finely divided state; much of the ore was of a loose cavernous structure, with quartz sinter and quartz stalactites occurring in hollows. Lower down masses of auriferous pyritic ore were met with. As shown in the above-mentioned plans, the bulk of the ore mass is nearly surrounded by dykes of coarse dolerite, whilst at the lower levels highly altered serpentine is met with, together with felspathic rocks and quartzite highly charged with pyrites. From the returns made, shown in the table below, it seems that the surface ore was very rich, carrying about 3 ounces of gold to the ton; below this came a zone of enrichment, when some of the ore must have yielded about double this amount, till with increasing depth the yield has fallen to little over 1½ ounces to the ton, which may be called its normal richness.

There have been various theories put forward to explain the mode of formation of this deposit, but not one of these can be looked upon as wholly satisfactory. Mr. R. L. Jack, Government geologist, looks upon this as a geyser deposit, basing his opinion upon the spongy condition of the ore, and upon the fact that much of the silica is combined with water. Another theory that has obtained much currency is that the mass was the gossan of a large body of pyritous ore, occurring at a lower level. Messrs. C. S. Wilkinson[1] and T. A. Rickard[2] incline to consider the deposit as being in the main a secondary one. The former describes the country rocks as being highly metamorphosed stratified rocks of Permo-Carboniferous age, containing iron pyrites, disseminated and in small masses; they are pierced by intrusions of hornblendic granite and porphyritic dolerite, the former being the older, and the deposition of the pyrites being associated with its intrusion. Subsequently, as water passed through the pyritous strata in the neighbourhood of these dykes, the dolerite became kaolinised, and the pyrites decomposed, the gold in it being dissolved and re-deposited along with the oxide of iron produced from the solution of the pyrites.

Mr. Rickard's explanation is less precise, but he too seems to consider that the deposition was connected with the intrusion of the igneous rocks, and that after its formation, later rock movements caused the circulation of fresh mineral-bearing solutions. So far Mr. Wilkinson's theory seems the most reasonable, but it is not quite

[1] "Notes on a Collection of Rocks and Minerals from Mount Morgan," *Records Geol. Survey of N.S.W.* 1891, ii. p. 86.

[2] "The Mount Morgan Mine," *Trans. Amer. Inst. Min. Eng.* xx. 1891, p. 133.

clear why he should infer that the payable ore is confined to the oxidised region. It is surely possible, to say the least of it, that the pyritic ore may prove to be payable; no doubt a zone of concentration exists in the oxidised gossany material, but this is so rich that it is still possible that the pyrites, though poorer, may yet be rich enough to admit of profitable working. This point can, however, only be settled by actual explorations.

The following are the results obtained by the Mount Morgan Gold Mining Company, Limited, since its inception:—

Half-year ending	Ore treated.	Gold got.	Average yield per ton.		
	Tons.	Oz.	Oz.	dwt.	gr.
Nov. 30th, 1886	6,440	19,476	3	0	11
May 31st, 1887	6,631	38,551	5	16	16
Nov. 30th, ,,	8,740	45,154	5	3	7
May 31st, 1888	8,501	45,469	5	6	23
Nov. 30th, ,,	12,600	66,805	5	6	0
May 31st, 1889	36,676	168,386	4	11	19
Nov. 30th, ,,	38,416	155,157	4	0	18
May 31st, 1890	37,799	103,793	2	14	22
Nov. 30th, ,,	37,848	113,252	2	19	20
May 31st, 1891	36,893	88,330	2	17	21
Nov. 30th, ,,	30,359	63,323	2	1	17
May 31st, 1892	29,430	60,974	2	1	10
Nov. 30th, ,,	29,966	59,490	1	19	16
May 31st, 1893	32,224	60,420	1	17	12
Nov. 30th, ,,	30,703	60,760	1	19	13
May 31st, 1894	34,373	57,871	1	13	15
Nov. 30th, ,,	40,152	61,573	1	10	16
May 31st, 1895	42,296	62,231	1	9	10
Totals	500,047	1,331,015	2	13	5

The total value of the gold thus obtained is close upon £5,500,000, whilst £3,800,000 have been paid out in dividends.[1]

In 1895[2] this gold-field was split up into the Rockhampton and the Crocodile gold-fields, the latter consisting of little except the Mount Morgan. The outputs of these fields are given as 1,416 tons of stone producing 1,431 ounces of gold, and 88,578 tons of ore yielding 133,137 ounces respectively during that year.

The next most important gold-fields are those of Gympie, which produced in 1894 a total of 111,168 ounces, of which 110,595 ounces were reef gold and the balance alluvial. The

[1] *Report of the Directors*, 30th July, 1895.

[2] *General Report on the Mining Industry of Queensland for* 1895, p. 12.

total number of miners employed was 1,394. The following are the results obtained by some of the leading mines:—

Name of mine.	Stone crushed.	Gold got.
	Tons.	Ounces.
The Phœnix	12,533	28,606
North Smithfield	6,596	16,957
North Glenmire	8,019	12,066
Phœnix Golden Pile	4,235	13,914

There are a large number of good mines in this field, and the quartz veins seem to go down and to be rich in depth. In 1895 [1] the output was only 78,026 ounces.

The last of the important gold-fields may be said to be the Croydon. In this field a total quantity of 81,208 ounces was obtained in 1894, the whole apparently from quartz mining, there being 968 miners at work. The above amount of gold was got from the treatment of 47,791 tons of quartz, which yielded 72,136 ounces, or at the rate of 1 oz. 10 dwt. 4 gr. per ton, and 11,646 tons of tailings, which gave 9,072 ounces of gold when treated by the cyanide process. In 1895 there were 40,026 tons of quartz put through, yielding 55,546 ounces of gold. Scarcity of water is assigned as the cause of the diminished output.[2]

The following tables, compiled from official sources, show the weight and value of the gold exported from Queensland from the beginning of 1861 to the close of the year 1895:—

Table showing the Weight and Value of Gold, the Produce of the Colony, Exported from Queensland during the Years 1861 to 1876 inclusive.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Oz.	£		Oz.	£
1861	1,077	3,928	1869	138,221	523,045
1862	189	625	1870	136,773	489,539
1863	3,936	14,802	1871	171,937	616,907
1864	22,037	83,292	1872	186,019	660,396
1865	25,339	92,938	1873	194,895	717,540
1866	22,916	85,561	1874	375,587	1,356,071
1867	49,092	189,248	1875	391,515	1,498,433
1868	165,801	593,516	1876	374,776	1,427,929
Totals				2,260,110	8,353,770

[1] *General Report on the Mining Industry of Queensland for* 1895, p. 13.
[2] *Ibid.* p. 16.

Table showing the Weights of Alluvial and Reef Gold produced in Queensland during the Years 1877 to 1895 inclusive.[1]

Year.	Alluvial.	Quartz.	Total.
	Oz.	Oz.	Oz.
To end of 1876	—	—	2,260,110
1877	164,778	188,488	353,266
1878	130,574	179,038	309,612
1879	107,402	181,154	288,556
1880	86,082	181,054	267,136
1881	70,821	200,134	270,955
1882	52,038	172,855	224,893
1883	35,327	177,460	212,787
1884	26,175	281,629	307,804
1885	21,936	289,005	310,941
1886	15,361	325,637	340,998
1887	21,700	404,223	425,923
1888	12,099	469,544	481,643
1889	10,287	728,816	739,103
1890	19,069	591,518	610,587
1891	16,021	560,418	576,439
1892	17,039	598,519	615,558
1893	19,292	597,648	616,940
1894	25,938	653,573	679,511
1895	28,792	602,890	631,682
Totals . . .	880,731	7,383,603	10,524,444

The value of this total at £3 10*s.* per ounce is £36,955,118.[2]

Copper.—We are without detailed information relative to the mode of occurrence of copper ores in Queensland, but the range of this metal in the colony is very considerable, extending as it does from West Moreton on the south up to the Cape York country in the north; and from the seaboard on the east far back into the western regions. Among the known localities which have produced copper the following may be mentioned, namely:—Peak Downs, Mount Perry, Copperfield, Mount Norma, Glen Prairie, Cloncurry, Kroombit, Edina, Cressbrook, Kennedy, Rawbelle, Mount Flora, Mount Orange, Mount Greentop, Charters Towers, Drummond, Boolboonda, Mount Harpur, Mount Gotthard, Ellandale, Great Blackall, Mount Clara, Teebar, Munna, Wolca, Normandy, &c.[3]

At the Peak Mine igneous and metamorphic rocks predominate, the Peaks giving the name to the locality being entirely composed of partially decomposed trachyte. An amygdaloidal dolerite

[1] *Annual Report of the Under-Secretary for Mines* 1895, p. 22.
[2] *General Report on the Mining Industry of Queensland for* 1895, p. 6.
[3] James Bonwick, *Resources of Queensland*, p. 104, London, 1882.

sometimes contains patches of copper ore, and some of the cupriferous traps are said to very closely resemble those of the Lake Superior copper mines. As early as 1870, 29,168 tons of 20 per cent. copper ores had been raised from this property. About that period a lode two feet in width, running east and west, was cut at a depth of forty fathoms from the surface and traced for a distance of 250 fathoms. This discovery was followed in 1873 by that of another lode containing large quantities of black oxide of copper. In five years the dividends, on a nominal capital of £100,000, reached the sum of £215,250, besides which £53,577 had been written off the value of the mine. The company had, however, subsequently, to contend with very serious difficulties; the land transport to the place of shipment was over 250 miles, and miners' wages ranged from three to four pounds per week. A decline either in the shipment of ore or in the price of copper, consequently, very seriously affected the undertaking, which was eventually closed. A mine has been worked at Mount Perry upon nearly vertical veins enclosed in granite, to a depth of 800 feet, but the position of the locality with respect to the port of shipment renders the transport of ores very expensive.

Very large quantities of copper ore occur in Palæozoic rocks at Cloncurry; many rich lodes are known, distributed over a radius of about 100 miles, the most important being those worked by the Great Australian Copper Company, which was at one time working on an extensive scale. The district is however unfavourably situated with regard to transport, being on the western side of the main dividing range and 500 miles from the shipping port of Townsville. This fact and the low prices recently ruling have practically closed the mines of this locality.

At the Kennedy Copper Mine, near Sandy Creek, west of the Star River, the lode shows a large outcrop in porphyry, and courses about 35° east of north. At the Great Northern Copper Mine, in the Upper Star basin, a lode occurs in clay slate between two masses of granite. In 1880 only three copper mines were working in the colony. Most of the copper ore got in 1894 came from the Herberton district, part from the neighbourhood of Watsonville, and part from a new township that has been called Calcifer, where the Irvinebank Company has several mines, whose product in that year was 200 tons of smelted copper.

The copper output has now fallen very low, although it shows a slight improvement on the immediately preceding years, as appears from the following table[1] of the amounts and values of the copper-ore production of Queensland.

QUANTITIES AND VALUES OF COPPER ORE PRODUCED IN QUEENSLAND SINCE THE YEAR 1860.

Year.	Copper ore.	Value.	Year.	Copper ore.	Value.
	Tons.	£		Tons.	£
1860	1	50	1878	547	35,126
1861	49	1,450	1879	567	34,791
1862	268	10,332	1880	326	20,137
1863	1,100	30,000	1881	331	19,637
1864	2,000	60,000	1882	1,724	14,982
1865	721	58,440	1883	1,800	21,080
1866	3,168	91,872	1884	1,653	30,872
1867	6,140	84,200	1885	1,340	18,920
1868	9,033	73,020	1886	900	7,000
1869	6,310	76,230	1887	1,010	7,600
1870	1,335	80,795	1888	1,126	9,248
1871	2,490	174,300	1889	1,079	12,000
1872	2,448	196,000	1890	185	3,000
1873	2,441	185,808	1891	98	865
1874	2,228	164,040	1892	81	2,461
1875	1,674	121,980	1893	297	3,822
1876	2,105	147,000	1894	415	9,582
1877	1,959	167,337	1895	434	13,097
Totals				59,420	1,987,074

TIN.—Mr. T. F. Gregory was, in July 1872, sent to report upon the tin-fields at the Severn River, in the district of Darling Downs South.[2] He describes the stanniferous area of Queensland, as far as was then known, as being comprised within the following limits. "Commencing on the main dividing range between the eastern and the western waters at Lucky Valley Gold-fields, near the head of the Condamine River, the northern boundary extends in a west-south-westerly direction for about twenty-five miles, passing fifteen miles south of the town of Warwick to the head of Pike's Creek on the Pikedale Run; from this point it is bounded by a slightly curved line extending south about twenty miles to the Severn River, three miles below the Ballandean Head Station, where it trends south-east for twelve miles further, meeting the boundary of New South Wales at the Tenterfield Run; thence the crest of the watershed which forms the boundary between the two colonies embraces it in a north-easterly and easterly direction,

[1] *Annual Report of the Under-Secretary for Mines for* 1895, p. 34.

[2] *Quart. Jour. Geol. Soc.* xxix. 1873, p. 1.

back to Lucky Valley, the area comprised being, in round numbers, five hundred and fifty square miles in extent. Of this area, however, only about two hundred and twenty-five square miles have hitherto been found sufficiently rich in tin ore to pay for working."

The physical and geological character of the whole of the area described is that of an elevated granitic table-land intersected by ranges of abrupt hills, the highest of which are about three thousand feet above the sea level; its eastern escarpment forms the watershed of the Clarence River, the northern that of the Condamine and the south-western that of the Severn and McIntyre Rivers. The richest deposits have been found in stream beds and in fluviatile flats on their banks, the productive ground varying from a few yards to five chains in width, but occasionally broken by rocky bars. In such cases large deposits are frequently lodged in the spaces existing between the various granitic boulders. The aggregate length of these stanniferous bands was estimated by Mr. Gregory at about one hundred and forty miles on the Severn River, and about thirty more on the tributaries of Pike's Creek. At the date of Mr. Gregory's report, the tin lodes which had been discovered had been but very imperfectly tested.

The discoveries of tin ore made about the end of 1879 and the beginning of 1880, in the Wild River and Great Western districts, entirely eclipsed all the previous ones. The Herberton Tin Mines are situated on the slopes and crests of spurs from a great granitic mountain range, which runs nearly north and south at a distance varying from forty to fifty miles from the coast. The tin claims are chiefly on the slopes of the mountains, which, at a distance of less than a mile, entirely surround the town. The summit of the range is on an average from six to seven hundred feet above the level of the Wild River.

According to the Rev. J. E. Tenison-Woods,[1] the workings are of three kinds:—

First, those in which the tin ore has been scattered on the surface of slopes beneath, and in the immediate vicinity of, a lode. The second kind of workings consists in quarrying out masses of tinstone occurring on the backs and outcrops of lodes. Such bunches are due to the retention, in its original position, of the cassiterite present in the veins, while the lighter impurities, with which it was originally associated, have been removed by dis-

[1] Rev. J. E. Tenison-Woods, *Report on the Wild River and Great Western Tin Mines* (*near Herberton*), Brisbane, 1881.

integration and the mechanical action of water. The third class of workings consists of ordinary mining, where shafts are sunk and levels driven.

As far as they have been hitherto explored, the lodes in this neighbourhood are both wide and exceedingly rich. They vary to some extent in their direction and dip, but are commonly nearly vertical. At Herberton the average direction will be somewhat east of north and west of south; but on the western side of the granitic range the average direction is, on the contrary, more frequently west of north and east of south.

The Herberton mines are on the Wild River, and on the eastern side of the granite range; but on the western side, at a distance of between six and seven miles, at the sources of the Tate and Wash Rivers, there is a second stanniferous area, known as the Great Western tin-field. The granites of both regions are essentially composed of orthoclase, quartz, and black mica, and the tin ore is sometimes accompanied by wolfram.

A peculiar feature of the metalliferous deposits of the Great Western area is the outcrop of several copper lodes, which sometimes carry rich ores; these have recently been the object of exploitation, as already mentioned. The following description by Mr. Jack of one of the localities which he visited will serve to convey some idea of the general richness of the deposits in this district:[1]

"Prospectors' Gully falls west-north-west into the Wild River. At the date of my visit the greater part of the bottom had been cleaned for about 1¼ mile up the gully and the wash-dirt stacked ready for sluicing. Here and there lay groups of boulders of tin ore gathered out of the wash-dirt, many of them nearly 100 lbs. in weight. These large boulders stopped about a quarter mile up the gully below a reef of quartz showing tin ore in large lumps, which is seen on the right bank of the gully striking S. 10° W. to N. 10° E. The wash-dirt in the gully above this lode is characterised by finer stream tin.

"Shortly above the lode the gully splits into three branches. Between the southmost and middle branches, lumps of ore, from the size of marbles to the size of eggs, strew the surface in astonishing quantities. Without moving from the spot one might easily gather a stone weight of ore almost anywhere by reaching out his two hands. The whole of the 'surface' here should pay well to wash. This surface ore leads up to the Great Northern Lode of

[1] R. L. Jack, *Geol. Survey of Northern Queensland*, 1881, p. 8.

the Prospectors. A shaft has been sunk on this to the depth of six to ten feet. Twenty-six tons of ore, containing 60 per cent. of tin, have been raised from this shaft and sold."

Observations made during this examination led Mr. Jack to the conclusion that the tinstone was originally in the form of disseminated crystals, which have become concentrated by the weathering of their matrix during a long period of sub-aerial denudation. Two distinct types of tin-bearing rock were met with, namely, quartz reefs, and eruptive dykes. Many of the latter are to be passed at various points along the rocks on the boundary between Queensland and New South Wales.[1]

The number of tin streams and tin mines in operation in the colony during the year 1881 amounted to 174, but no deep leads appear to have been worked under the basalt.

In 1894, about two-thirds of the year's production, namely, 1,960 tons of black tin, came from the Herberton district, Irvinebank and Watsonville being the chief producers of lode tin, and Tate and California Creek of stream tin. The total amount of the former was 1,250 tons, the product of 7,212 tons of stone crushed, whilst the quantity of alluvial tin ore was 710 tons. The same district also produced 67 tons of wolfram ore. The following table[2] shows the quantities and values of tin ore produced in this colony since 1872, the first year in which any output of this metal is recorded :—

AMOUNT AND VALUE OF BLACK TIN PRODUCED IN QUEENSLAND FROM 1872 TO 1895 INCLUSIVE.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Tons.	£		Tons.	£
1872	1,407	109,816	1884	3,383	130,460
1873	8,938	606,184	1885	3,253	151,871
1874	5,702	358,550	1886	3,153	162,124
1875	4,475	237,879	1887	3,279	217,389
1876	4,315	187,201	1888	3,586	200,019
1877	3,335	133,432	1889	3,033	156,406
1878	2,849	88,366	1890	2,970	154,963
1879	2,877	120,391	1891	2,236	116,387
1880	2,847	142,977	1892	2,389	123,098
1881	3,456	193,699	1893	2,434	106,953
1882	4,261	269,904	1894	2,871	102,277
1883	3,346	187,292	1895	2,114	68,133
Totals				82,379	4,325,771

[1] *Proceedings Royal Geogr. Soc.* v. 1883, p. 101.

[2] *Annual Report of the Under-Secretary for Mines for* 1895, p. 34.

OTHER METALS.—The colony has for many years produced varying, but usually small, quantities of antimony. In 1894 the only district that produced any was the Hodgkinson, where 28 tons, valued at £280, were obtained. None was obtained in 1895.

Silver lead ores are also worked in several places, the Herberton district with 78,343 ounces of silver, and the Stanthorpe with 85,067 ounces, having been the chief producers in 1894. Nothing can be gathered as to the character of the ores mined in these districts, or of the mode of their occurrence. It is strange that in so many parts of the world silver ores and tin ores occur in the same districts, but it would appear that in this colony the ores occur in separate lodes and not, as far as can be gathered, in any way connected with each other. Most of the mines appear to be working on lodes of argentiferous galena, but rich ores, chiefly hornsilver and silver fahlore, are known at Silverfield. Hornsilver also occurs in the Herberton district, togther with galena. The latter occurs at Ravenswood and Sellheim River Field. The same two districts were again the chief producers in 1895; at Herberton, Mount Albion was the most important. The district produced 59,911 ounces, worth £8,237, the product of 2,037 tons of ore, which also yielded 278 tons of lead and 63 of copper alloy. In Stanthorpe district, the Silver Spur Mine, close to the New South Wales border, is doing good work, and produced 3,134 tons of ore, valued at £14,330.

The following table shows the quantities and values of metallic minerals other than gold produced in the years 1894 [1] and 1895 [2]:

Product.	1894		1895	
	Weight.	Value.	Weight.	Value.
		£		£
Silver	183,158 oz.	22,077	225,019 oz.	30,042
Tin Ore	2,871 tons	102,277	2,114 tons	68,133
Lead Ore	451 ,,	4,370	363 ,,	3,634
Copper Ore	415 ,,	9,582	434 ,,	13,097
Bismuth Ore	65 ,,	6,270	58½ ,,	3,258
Antimony Ore	28 ,,	280	—	—
Wolfram Ore	105 ,,	710	45 ,,	542
Manganese Ore	140 ,,	400	355 ,,	1,103
Total Values . . .		145,966		119,809

[1] *Annual Report of the Under-Secretary for Mines for* 1894, p. 29.
[2] *Ibid.* for 1895, p. 31.

South Australia.

Mining operations have, for many years, been extensively carried on in various parts of South Australia, the most important minerals hitherto found being ores of copper. Gold, although to some extent present in the majority of its rivers and streams, is by no means abundant. With regard to the mode of occurrence of argentiferous lead ores, which have been produced in considerable quantities, we are without detailed information. Until comparatively recent times South Australia had been without a Government geologist, and consequently but little is accurately known of its geology; while with regard to its mineral productions we have scarcely any information beyond that supplied by various statistical tables.

Gold.—Mr. G. H. F. Ulrich, who visited South Australia in the year 1872, describes the principal localities in which gold mining was then being carried on; the most important gold-fields being the Ulooloo, the Blumberg, the Barossa, and the Echunga, but gold was also obtained at the Jupiter Creek Diggings and elsewhere.[1] The first record of gold exportation is in 1873, when 76½ ounces were returned for export.

The Ulooloo[2] gold-field, discovered in 1870 or 1871, is situated some twenty-five miles north of the celebrated Burra Burra Copper Mine, within an area forming part of the extensive northern region which has been proved to be rich in copper ore, but in which the existence of gold was at one time thought doubtful. The rocks throughout this portion of the field consist of flaggy, gray, brown, and bluish slates, alternating with massive quartzites and gritty sandstones. All these rocks are traversed by quartz veins, apparently in all respects similar to those met with several hundred miles further north, which have been regarded as exhibiting an auriferous aspect, but no quartz reefs have as yet been worked. Unfortunately, however, the non-discovery of fossils in the rocks of either of these localities precludes the possibility of establishing their geological relations. This field contains numerous deposits of auriferous shingle brought down from the surrounding ranges, and these may be divided into three classes, recent gold drift in existing creek beds, an older drift in ancient watercourses, and an old Tertiary gold drift.

The more recent deposits are shingly drifts occupying the beds of creeks which have been for the most part eroded to the depth

[1] *Mineral Resources North of Port Augusta*, p. 19, Adelaide, 1872.

[2] H. Y. L. Brown, *Report on the Ulooloo Goldfield*, 1887.

of several feet in slaty rocks, and, as the surfaces of these gullies are generally rendered very uneven by joints and fissures along cleavage planes, the collection of the wash-dirt becomes a slow and troublesome operation. The older deposits, on the other hand, form banks of from 6 to 30 feet in depth, chiefly composed of clay, sand, and shingle, lying between the principal and branch creeks. These are generally richer in gold than those belonging to the other class. The principal diggings at Ulooloo extend for a distance of about a mile up a main branch of the creek, and the slightly water-worn character of the gold found would appear to indicate that the reefs whence it was originally derived cannot be situated at any considerable distance. There is but one small patch of Tertiary drift known, namely, at the White lead, consisting of conglomerate and cement, which has escaped denudation.

In 1886 there were from 80 to 100 men engaged in digging on this field. No information as to its yield is available.

The rocks of the Blumberg gold-field are partly of an eruptive and partly of a metamorphic character. They consist of mica schist, hard micaceous quartzites, sandstones, and flagstones, and are traversed by eruptive dykes and by protrusions of a very coarse-grained granite characterised by containing large crystals of white mica. The alluvium here varies from three to five feet in thickness, and at the surface consists of brown and yellow mottled sands and clays, beneath which is a layer of from one to two feet in thickness, consisting of a mixture of clay and angular quartz-gravel resting on a soft bottom composed of mica schist. Wherever this thins out, the surface is, as a rule, found remuneratively auriferous up to a spot covered with numerous loose blocks of quartz. The gold is throughout of a crystalline spongy character, and must have been derived from reefs in close vicinity to the diggings. Some of the samples of alluvial gold from this field resemble the so-called spider-leg gold from the northern gold-fields of Queensland, which there occurs not only in the drifts but also in elvan dykes and greenstone. In this district various quartz reefs have from time to time been worked, but not generally with satisfactory results.

The Barossa gold-field is said to exhibit in its topographical and geological features a close resemblance to some of the Victorian fields where the protective covering of basalt is absent. The principal deposit is probably of Pliocene age, consisting of rounded quartz pebbles, and boulder drifts, enclosing layer-like patches of ferruginous quartzose conglomerate. Both the older and more recent drifts are auriferous; but various circumstances go to show that the gold in the latter was mainly derived from the disintegration of the former. From the fact that a portion of the gold found in the more recent alluvium is less water-worn than is that from the older, it was considered probable that auriferous quartz reefs exist within the limits of this gold-field, and such have actually been discovered at Moonta Hill and other places, but they have not yielded encouraging results.

In the Para Wirra gold-field,[1] which adjoins Barossa, the rocks are also of Lower Silurian age. Deep leads are known, chiefly on the north side of the Devil's Gully, but they are for the most part in hard cement, and, though they carried small nuggets up to 1 oz. in weight, were never payable. The alluvial diggings are very limited in extent, and appear to have derived their gold from the deep leads they cut through. Some of the reefs have given satisfactory results, notably the Lady Alice Mine, which, discovered in 1871, was only sunk upon to a depth of 160 feet, when it was closed down in 1879. From the flotation of the company to work it in 1873 to the time work was stopped, this mine produced gold to the value of £22,000 and copper to that of £4,000; the latter metal occurs native, as sulphide and as oxide. The main reef, striking about N. 10° E. and dipping E., was poor except where it was intersected by a smaller spur dipping N.E. The country strikes about N., and is highly metamorphosed, gneissic granite being the prevailing rock.

At Echunga the geological features of the country closely resemble those occurring at Barossa, namely a drift of probably older Pliocene age, composed of rounded quartz pebbles, ordinary drift and conglomerate, occupying the slopes and summits of tolerably high ranges. Some of the quartz leads in this gold-field have been rather extensively prospected. It is said to have been discovered in 1852.

About 1890 some important gold reefs were discovered at Wadnaminga, some fifteen miles south-east of the Mannahill station, and these have since then been systematically worked. It is semi-officially stated that up to the 10th December, 1881, 130,000 oz. of gold, valued at £450,000, had been exported from the colony. The following table [2] shows the exports of gold from the colony between the years 1881 and 1895:—

[1] H. Y. L. Brown, *Notes, &c., explanatory of Geological Map of Para Wirra and Barossa Reserves*, No. 178, 1885.

[2] *South Australia, Statistical Register* and MS. information.

Table showing the Export of Gold, the Produce of the Colony, from South Australia from 1881 to 1895 inclusive.

Year.	Quantity.	Value.
	Oz.	£
1881	220	880
1882	764	3,080
1883	2,671	10,534
1884	3,970	15,469
1885	4,692	18,295
1886	8,825	32,535
1887	19,082	72,003
1888	8,728	34,205
1889	10,124	37,305
1890	5,184	20,808
1891	6,904	27,380
1892	6,569	26,097
1893	3,262	12,561
1894	8,904	33,401
1895	7,473	26,060
Totals	97,572	370,613

Northern Territory.—Mr. J. A. Plunkett states that, although a large amount of money had been expended in quartz reefing in the northern territory, and a good deal of quartz had, in the aggregate, been raised and crushed, quartz mining had not been fairly tried. Many claims have been superficially tested, while not a sufficient number of them has been systematically worked. The average yield from the commencement would, however, he believed, exceed one ounce of gold per ton of stone crushed.[1]

The principal reefs to which attention has been directed, taking them in order from north to south, are the following:—The Stapleton Reefs, the Howley Reefs, the Britannia Reef, the Yam Creek Reefs, the Extended Union Reef, the Union and Lady Alice Reefs, the Pine Creek and Maude Reefs. Of these the Union and the Lady Alice Reefs, with the Pine Creek Reefs, are the only ones which have been worked upon anything like an extensive scale. With the exception of one or two reefs which run nearly due north, their course is either north-westerly or north-north-westerly, and in some cases they can be traced for a considerable distance. The gold-bearing district is known to extend over a length of 120 miles from north to south, and a width of 20 miles from east to west,[2] within which area gold-bearing deposits have

[1] *South Australia*, edited by William Harcus, p. 169, London, 1876.

[2] J. D. Woods, *The Province of South Australia*, 1894, p. 432.

been found. The most important are still the Union and the Lady Alice reefs.

In the year 1875 the total result obtained from thirty-three distinct crushings of quartz from the northern territory of South Australia was as follows:—

Quartz treated, 2,732½ tons; gold obtained, 4,327 oz. 18 dwt., or a little more than 1 oz. 12 dwt. of gold per ton of stone treated.

The gold exported through the Customs[1] for the eleven years from 1881 to 1892, amounted to 261,070 oz., valued at £919,700. Much however has probably been carried away without being reported. The following are the details of the exports for 1891, 1892, and 1893:—

	1891.		1892.		1893.	
	Weight.	Value.	Weight.	Value.	Weight.	Value.
Gold	28,629 oz.	£98,149 ...	31,588 oz.	£108,763 ...	31,277 oz.	£108,110
Gold ore and concentrates	26 tons	£552 ...	23 tons	£430 ...	2 tons	£20

The total output for 1895 is given as 47,343 oz. for the whole of South Australia.

Copper.—The history of copper mining in South Australia dates from the year 1843, when the Kapunda Mine was discovered on a sheep run, fifty miles north-east of Adelaide. Smelting for regulus was commenced in 1849, and the process was subsequently extended to the manufacture of fine copper. The Burra Burra Mine was discovered about two years after the Kapunda, from which it is distant some forty-eight miles in a northerly direction. The total quantity of ore raised from the Burra Burra Mine during the twenty-nine and a half years of its existence[2] was 234,648 tons, giving an average produce of 22 per cent., equal to 51,622 tons of copper, and worth £4.749,224. It ceased working in 1877.

There are two lodes at Burra Burra, both striking north-west and south-east and dipping north-east at an angle of about 70°. The rock forming the foot wall of Allen's Lode is a "serpentinous limestone," massive and compact, while the rock on the hanging side of Kingston's Lode is composed of very thin, highly inclined beds of non-fossiliferous limestone. The veins would seem to come under the class of contact veins, but as no workings were made south of their junction, and no section of the country rock exists, the evidence on this point cannot be regarded as complete. The

[1] *The Province of South Australia*, 1894, p. 432.

[2] J. D. Woods, *The Province of South Australia*, 1894, p. 257.

main engine shaft is sunk to a depth of 100 fathoms from the surface, and there is no adit. Blue and green carbonates continued to a depth of from forty to fifty fathoms. Red and other oxides of copper as well as metallic copper were also found more or less within these limits. Between the 50- and 60-fathom levels large horses occurred containing vein material and ore. A little below the 70-fathom level erubescite was found, while between the 90- and 100-fathom levels the first discovery of copper pyrites was made.[1]

For many years the Burra Burra was probably the richest copper mine in the world, but, in 1860, the discovery of the Wallaroo Mine, Port Wallaroo, and shortly after of the Moonta Mine, on Yorke's Peninsula, within the next two years brought formidable rivals into the field. The development of the Wallaroo Mines was exceedingly costly, and a large amount of capital, amounting to some £80,000, was expended before any adequate returns had been made. Since the year 1860 its progress has however been satisfactory, the lodes being in many places extraordinarily large and productive, sometimes measuring nearly thirty feet in width of almost solid ore, containing 12 per cent. of copper, and yielding as much as sixty tons of ore per running fathom. The width of the lodes is, however, usually from five to ten feet.

There are three distinct lodes at the Wallaroo Mines, all of which are enclosed in porphyrite. They strike about 20° S. of E. and are nearly perpendicular down to the 80-fathom level. These lodes consist of a series of large lenticular masses connected by narrow partings in the country rock. There are many cross divisions against which the ore often terminates, as well as others which slightly shift the lodes. The principal ores to a depth of 15 fathoms are carbonates of copper; black sulphides between the 15- and 25-fathom levels; and copper pyrites from the 25-fathom level downwards. The porphyrite, which is the country rock, is often capped by limestone, and the ores on an average assay about 12 per cent. of copper.

Including Matta and Kunilla,[2] the drives and levels extend to a length of twenty miles, and there are thirty shafts, the deepest of which is down to 195 fathoms. From the opening of the mine in 1886, the total quantity of ore raised was 451,016 gross tons of 21 cwt., worth £2,030,143.

[1] MS. notes furnished by Mr. J. Darlington.

[2] J. D. Woods, *The Province of South Australia*, 1894, p. 258.

About a year subsequent to the discovery of the Wallaroo Mine, a still more valuable find of copper ore was made eleven miles to the south-west of it, and about two miles from the coast. A quantity of small fragments of green carbonate of copper having been found lying on the surface of the ground, pits were sunk, and a fine lode of copper ore was met with at a very inconsiderable depth. This was the commencement of the now celebrated Moonta Mine. At this mine highly inclined masses of porphyrite are covered by a layer of conglomerate, varying from one to three feet in thickness. On this reposes a bed of stiff red clay resulting from the decomposition of porphyrite, between four and five feet in depth, covered by two feet of limestone, above which are a few inches of sand and gravel. The principal lodes, which vary from six inches to twenty feet in width, are three in number, namely: the Main Lode coursing 20° N. of E., with an underlie of from two to three feet per fathom west; Young's Lode, with a direction of 40° E. of N., and an underlie of from three to five feet in a fathom west; and Dominick's Lode, coursing 40° E. of N., and underlying from four to five feet per fathom west. The distance between Young's Lode and the Main Lode is from 800 to 900 fathoms, and between the former and Dominick's Lode from 70 to 80 fathoms. Other lodes are sometimes recognised, but it is probable that they are all either branches or prolongations of the above. There are some thirty miles of levels,[1] and seventy-seven shafts, the deepest being down 287 fathoms. The average yield of the dressed ore is about 18 per cent. During the first twenty months after the opening of the Moonta Mine, 8,000 tons of ore, averaging nearly 25 per cent. of fine copper, were raised, and dividends amounting to £64,000 were paid from the proceeds. The average yearly return from the commencement up to 1876 was 18,220 tons of ore, of an average yearly value of £197,270. From its start up to June 30th, 1886,[2] there had been raised 476,180 gross tons (of 21 cwt. each) of ore, worth £4,579,097. This mine is now amalgamated with the Wallaroo Mine. There are various other mines in the neighbourhood of the Moonta, which have been worked with more or less successful results.

Copper mines have been opened in two or three localities near the River Murray; and at Callington, about thirty-six miles from Adelaide, in the direction of the Murray, a copper mine has been working for many years with a moderate degree of success. A few

[1] J. D. Woods, *The Province of South Australia*, 1894, p. 259

[2] *Ibid.*, p. 259.

miles from this is the Huel Ellen Mine, situated about three miles from the town of Strathalbyn, which was originally worked for argentiferous lead ores. The lead ore ultimately gave place to oxide of copper, but the mine is believed to be at present unworked. One of the most promising copper mines of the colony is the Blinman, which has been a large producer; it is worked on a strong lode which carried carbonates of copper near the surface, and sulphides with a gangue of calcspar and barytes, with but little quartz in depth.

The most extensive mineral district of the colony is that lying north, north-east, and east of Port Augusta. Here the unaltered sedimentary rocks composing the tract of country from the Burra Burra Mine northward, show as a whole a remarkable uniformity in their lithological characters. The same rocks, consisting of quartzites, slates and shales of various textures, sandstones, conglomerates, and siliceous limestones, recur again and again in grand anticlinal and synclinal undulations over hundreds of miles. As no traces of organisms have anywhere been found in these strata, the geological age of the rocks has not been accurately determined, but Mr. Ulrich, who visited this region in 1872, unhesitatingly assigns them to one of the older epochs of the Palæozoic period. As a rule, this region has the disadvantage of being barren and comparatively waterless. Timber for mining purposes is absent, and communication with the seaboard is difficult and expensive.

In this area copper ores occur as impregnations, in pockets, in layers, and in lodes of various kinds, but, speaking generally, Mr. Ulrich does not appear to have formed a high opinion of its capacity as a mining district.

There were nineteen copper mines in operation during the year 1881, namely:—Yudanamutana; Blinman; at Dora; the Devon Consols Co.; the Hamley Mining Co.; at Kapunda South; at Moonta; the Wallaroo Co.; the Yorke's Peninsula Mining Co.; the Huel Friendship Mine; the Kunamundoo Mine; the Garrett Mine; Leigh's Creek; Nildotte; Beltona; Voca Vocina; Gammon's Creek; Mount Rose, and North Mount Rose. Copper ores are the most important minerals of South Australia, and upon the yield of its copper mines the prosperity of the colony to no small extent depends.[1]

The following table, compiled from official sources, shows the weight and value of the copper, copper ore, and regulus, exported

[1] *The Australian Handbook*, London, 1883, p. 373.

from South Australia from the commencement of 1856 to the end of 1895 :—

Table showing the Quantity and Value of Copper, Copper Ore and Regulus, the Produce of the Colony, exported from South Australia during the following Years :—

Year.	Ingots.			Ore and regulus.		Total value.
	Quantity.		Value.	Quantity.	Value.	
	Tons	cwt.	£	Tons.	£	£
1856	2,219	0	248,460	9,539	159,205	407,665
1857	2,844	13	290,739	8,115	144,245	434,984
1858	2,389	16	250,042	6,851	109,040	359,082
1859	2,837	5	289,841	7,447	107,399	397,240
1860	3,271	9	331,775	8,335	104,007	435,782
1861	3,052	7	294,572	8,207	152,874	447,446
1862	4,293	12	400,591	6,634	143,781	544,372
1863	4,802	0	477,944	5,382	84,917	562,861
1864	6,702	15	637,791	4,597	40,605	678,396
1865	5,009	16	433,795	16,176	184,677	618,472
1866	6,463	12	584,509	16,824	225,683	810,192
1867	7,843	3	627,384	11,455	113,969	741,353
1868	5,211	7	400,691	20,735	207,732	608,423
1869	4,639	8	371,566	26,835	250,259	621,825
1870	5,471	1	394,919	20,886	173,861	568,780
1871	6,395	11	518,080	20,127	119,903	637,983
1872	7,452	10	680,714	26,964	122,020	802,734
1873	7,087	4	635,131	27,382	133,371	768,502
1874	6,629	7	557,306	22,854	136,530	693,836
1875	6,841	15	578,065	26,436	175,101	753,166
1876	5,463	9	427,403	22,682	164,597	592,000
1877	5,143	11	396,602	18,532	165,408	562,010
1878	3,594	6	252,206	17,007	155,381	407,587
1879	3,368	10	217,186	13,715	134,202	351,388
1880	3,255	8	233,374	14,622	112,773	346,147
1881	3,824	5	263,370	21,638	154,926	418,296
1882	3,647	15	259,884	25,897	195,686	455,570
1883	3,398	15	234,780	18,687	140,545	375,325
1884	4,572	1	287,753	23,968	181,477	469,230
1885	3,517	12	194,090	18,639	128,893	322,983
1886	3,635	11	172,330	14,782	58,538	230,868
1887	3,874	10	186,624	12,695	53,709	240,333
1888	3,165	10	252,627	12,873	73,575	326,202
1889	4,008	12	212,933	17,730	83,969	296,902
1890	2,961	17	155,417	15,380	92,562	247,979
1891	3,551	13	182,142	13,035	53,675	235,817
1892	2,653	14	132,040	10,506	43,485	175,525
1893	4,319	13	208,967	1,259	5,808	214,775
1894	4,944	8	208,639	309	4,884	213,523
1895	5,167	12	226,494	212	1,607	228,101
Totals	179,526	3	13,708,776	595,949	4,894,879	18,603,655

Northern Territory.—Copper was first found in 1873 near Pine Creek, but was not worked here till 1889. Other mines have been opened near the Daly River. Between the years 1886 and 1892 the total export of copper ore was 3,171 tons[1] valued at £38,702. In 1891 there were 268 tons, value £3,642; in 1892, 168 tons, value £2,155; and in 1893, 135 tons, value £1,190, exported from the Territory.

Lead and Silver.—No lead ores, properly speaking, are worked in the colony for lead alone, only argentiferous lead ores being apparently considered worth working; on the other hand silver ores that are not lead-bearing are exceedingly rare, so that these two metals must be considered together. Chlorides and iodides of silver[2] are, however, known in the Ediacara, Fifth Creek Central, Mount Malvern, Eagle and a few other mines; silver occurs in iron oxides at Buttamuk Mine. In most of the other very numerous localities in which silver ores are known, these are almost always argentiferous galena or cerussite; arseniates and phosphates of lead also occur. These ores are sometimes associated with ores of copper. They generally occur in fissure lodes in Primary rocks, the chief veinstones being barytes, calcite, quartz, ironstone, &c. There is an exceptional occurrence at the Ediacara Mine, where silver-lead deposits occur as irregular masses in a soft argillaceous bed, and where crystalline dolomitic limestones carry veins of galena and cerussite with, in places, fahlore.

The principal mines of argentiferous galena are situated in the southern portion of the colony near Cape Jervis. Among the most important are the Talisker, George, and Campbell's Creek Mines. Lead ores have also been found near Kapunda; and several years ago galena was found in the hills twenty miles south-east of Adelaide in the Almanda Mine, which had been originally opened as a copper mine. Rich silver ores were found, but the influx of water at the moderate depth of 20 fathoms was so great that the pumping plant at the mine proved inadequate, and work had to be suspended.

The following table shows the quantity and value of the lead and lead ore annually exported from South Australia during forty years. A considerable proportion was the produce of the Huel Ellen Mine, near Strathalbyn, but we are without any detailed information relative to the mode of occurrence of lead ores in that district. Silver lead and silver ores are widely distributed, and it will be remembered that the great Broken Hill Mines are only 16 miles east of the boundary between New South Wales and South Australia.

[1] H. D. Wilson, *The Northern Territory*, Adelaide, 1894, p. 434.

[2] H. Y. L. Brown, *Catalogue of South Australian Minerals*, Adelaide, 1893, p. 27.

Table showing the Quantity and Value of Lead and Lead Ore, the Produce of the Colony, exported from South Australia from 1856 to 1895 inclusive.[1]

Year.	Lead.			Lead ore.		Total value.
	Quantity.		Value.	Quantity.	Value.	
	Tons	cwts.	£	Tons.	£	£
1856	—		—	33	377	377
1857	—		—	1,422	23,855	23,855
1858	—		—	853	14,200	14,200
1859	63	1	5,710	262	8,068	13,778
1860	91	4	8,275	68	2,480	10,755
1861	62	16	4,426	15	300	4,726
1862	21	6	981	97	2,260	3,241
1863	13	11	525	450	9,007	9,532
1864	3	3	121	566	13,107	13,228
1865	4	2	133	86	1,507	1,640
1866	67	11	2,991	648	11,318	14,309
1867	169	11	5,464	212	3,353	8,817
1868	152	9	5,670	76	1,245	6,915
1869	146	16	4,471	24	296	4,767
1870	128	4	4,089	3	21	4,110
1871	169	1	5,497	—	—	5,497
1872	—		—	61	2,324	2,324
1873		14	20	—	—	20
1874	—		—	24	332	332
1875	—		—	132	66	66
1876		11	14	17	215	229
1877	18	11	295	6	120	415
1878	—		—	—	—	—
1879	3	0	90	—	—	90
1880	—		—	—	—	—
1881	—		—	90	1,182	1,182
1882	—		—	82	2,111	2,111
1883	—		—	907	13,757	13,757
1884	—		—	386	5,898	5,898
1885	7	12	137	37	1,496	1,633
1886	1	8	18	34	602	620
1887	13	10	123	120	1,800	1,923
1888	138	15	1,973	171	2,550	4,523
1889	257	5	2,942	328	2,332	5,274
1890	—		—	523	8,452	8,452
1891	—		—	128	1,787	1,787
1892	29	0	334	74	521	855
1893	20	7	185	34	420	605
1894	3	14	34	—	—	34
1895	4	4	39	2	11	50
Totals	1,5876	4	54,557	7,971	137,370	191,927

Northern Territory.—Several lodes of silver-lead ore have been worked since about 1887, the most successful being the Eveleen Mine, about 30 miles from the Union railway station, and

[1] From the values affixed it is evident that the lead and lead ores must have been argentiferous, and probably also contained gold.

a group of mines near the McInlay river. From this group of mines up to 1892 there had been shipped nearly 1,200 tons of ore, worth £46,567, the ore varying from 50 to 65 per cent. of lead and 40 to 150 ounces of silver to the ton. In 1892 the Territory shipped 112 tons of ore, valued at £1,640, and in 1893, 10 tons, valued at £150. Nothing is known about the geological relations of these deposits.

Other Metals.—Stibnite occurs in South Australia, and from 1865 to 1875, 390 tons of bismuth ore, of the value of £14,700, were shipped from the colony. Since that time very little, if any, bismuth ore has been shipped, the first parcels not having proved very remunerative.

Tin occurs in several places, and small parcels are shipped from time to time; between the years 1880 and 1894, tin ore to the value of £860 seems to have been exported. In the Northern Territory,[1] both stream tin and lode tin have been discovered throughout a district some 150 miles in length, Mount Wells being the best known locality. The first shipment was made in 1882 and from then to the end of 1892 the quantity exported was 466 tons, worth £22,834; in 1893, 29 tons, worth £1,595 were exported. Nickel and cobalt ores are known to exist, but have not been worked. Several localities where manganese occurs are known, and at Boolcunda, manganese deposits have been pretty extensively worked; since 1880 manganese ores to the value of about £42,000 have been shipped. In 1893 the output was 2,428 tons, valued at £6,359, in 1894 it was 174 tons, valued at £517, and in 1895 only 48 tons, valued at £146. Large deposits of iron ore of high quality are reported to occur in several places, but beyond a little desultory work, nothing has been done in the way of opening them out.

A good deal of zinc ore is raised in the Colony; between the years 1878 and 1894, zinc to the amount of 522 tons, valued at £10,379, was exported. In 1894 the quantity exported was 38 tons, valued at £472.

Western Australia.

Gold.—Although small patches of more or less auriferous drift occur in various localities scattered over this portion of the Australian continent, gold has only been discovered comparatively recently in

[1] *The Province of South Australia:* H. D. Wilson on the Northern Territory, 1894, p. 434.

paying quantities. Among other places it occurs at Peterwangy, in alluvial detritus, the bed-rock consisting of granulite intersected by trap dykes, and towards the lower ground overlain by beds of nodular ironstone, sandstone, and grit. The result of prospecting in this place was the discovery of some minute specks of gold in quartz enclosed in greenstone. Quartz veins, varying from the width of a sheet of paper to several feet in thickness, are found traversing the older rocks, wherever they reach the surface, but do not extend into the more recent formations. The quartz enclosed in granite is usually more transparent than that of veins traversing sedimentary rocks, which frequently bears a close resemblance to the veinstone of the auriferous reefs of Victoria, and often contains considerable quantities of iron pyrites. The general strike of these veins varies from north and south to north-east and south-west, in which directions they may sometimes be traced for long distances.

About the year 1887, some rich finds of gold were made in the extreme south of the Colony, and in a wonderfully short time an immense number of gold-mining companies were formed, a veritable mania for these having set in in England; so much so, that in 1894 there were over a hundred registered in London, with a nominal capital of nearly eight and a half millions sterling. Their inception may be said to date from 1891, and by 1896 a great deal of mining was being done, although the depth attained by any of the mines was still inconsiderable. This movement was greatly helped by the surface richness of many of the mines, as for instance Bailey's Reward, which yielded at first at the rate of 15 ounces to the ton, although subsequent crushings gave a very much smaller return, having dropped to 15 pennyweights in 1896. By the end of 1894 the following gold-fields were officially[1] declared :—

Kimberley	47,000	square miles.
Pilbarra	32,000	,,
Ashburton	8,200	,,
Murchison	32,000	,,
Yilgarn	24,000	,,
Coolgardie	21,500	,,
East Coolgardie	44,200	,,
Dundas	16,000	,,
Total area	224,900	,,

[1] *Report on the Department of Mines, Western Australia, for* 1894, p. 4.

The reports of the Department of Mines give the most meagre information as to the nature of these deposits. The most valuable publication on them so far is a report by Bergrath Carl Schmeisser[1]; according to him the deposits, in addition to alluvial, occur in two distinct forms, quartz fissure veins, and what are known in West Australia as *lode formations.*

The strata composing the gold-fields appear to consist of metamorphic rocks, such as slates, quartzites, chloritic schists, &c., steeply inclined, striking about N.N.E.—S.S.W., and overlying granitic rocks. Numerous dykes of diorite and diabase of great extent and thickness traverse both the granite and the sedimentary rocks in a direction about parallel to the strike of the latter; dykes of felsitic porphyry also occur, but less commonly than the two first-named eruptives. All these eruptive rocks, together with the granite, have been decomposed to depths of between 70 and 150 feet, being changed into more or less pure kaolin. All these rocks, sedimentary and igneous, are traversed by numerous veins of quartz, coursing approximately north and south, or within a few degrees on either side of this bearing, with a prevalent dip to the west, many of these veins occurring in groups. They vary greatly in width, from a few inches to 30 or, exceptionally, 80 feet. There is often a want of regularity both as regards continuity in length and permanence in depth, whilst some of the deposits are of a lenticular character; contact deposits are occasionally met with.

The so-called lode formations, which may be provisionally classed as stockworks, consist of more or less altered country rock, intersected by a network of small veinlets of quartz; they occur chiefly in diorite and diabase. Their thickness is considerable, varying from a few feet to over a hundred, and they often pinch out entirely. The more numerous the quartz veinlets and the more cellular the character of the quartz, the richer is the deposit.

The footwall is usually the better defined, the hanging wall generally—though occasionally the footwall also—passing gradually into the normal country rock. Slickensides are often met with. There are also instances of dykes of felspathic porphyry, much decomposed, being intersected by a network of quartz veinlets. Schmeisser states that both the quartz veins and the stockwork-like deposits occupy fault-fissures. In the latter case he considers that great masses of country rock have been included in these faults, crushed and triturated, thus affording ready access to mineralising solutions.

[1] "Die gegenwärtige Lage des Goldbergbaues in Westaustralien," *Zeitschrift f. Prakt. Geol.*, 1896, p. 174.

Both the fissure veins and the veinlets of the stockworks are filled with quartz, carrying free gold; in depth, iron and arsenical pyrites, and occasionally galena and copper pyrites are met with. The richness of the quartz veins is very variable, and there is a strong tendency for the gold to run in *chutes*, dipping in the direction of the strike of the deposit. The outcrops are often very rich either in continuous stretches or in pockets, whereas the ore in depth gets very much poorer, even to barrenness. It is worth recording that in a little quartz vein on the Devon Consols claim, near the Black Flag, at six feet below the surface, a mass of gold weighing 303½ ounces, and nearly free from any admixture of quartz, was met with. Schmeisser points out that nothing definite can be said as yet as to the probability of these deposits being permanent in depth. The following table,[1] from official sources, shows the quantity and value of gold obtained since 1886:—

Quantity and Total Value of Gold, the Produce of Western Australia, entered for Export from 1886 to 1895 inclusive, showing the Quantity obtained from each Gold-field.

Year.	Kimberley.	Pilbarra.	Yilgarn.	Ashburton	Murchison	Dundas.	Coolgardie.	Totals.	
	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	£
1886	302	—	—	—	—	—	—	302	1,148
1887	4,873	—	—	—	—	—	—	4,873	18,517
1888	3,493	—	—	—	—	—	—	3,493	13,273
1889	2,464	11,170	1,859	—	—	—	—	15,493	58,872
1890	4,474	16,055	2,277	—	—	—	—	22,806	86,664
1891	2,699	11,875	12,833	839	2,064	—	—	30,311	115,182
1892	1,089	12,893	21,209	—	24,357	—	—	59,548	226,284
1893	1,621	11,698	75,745	468	21,211	148	—	110,891	421,385
1894	589	16,255	31,498	285	52,946	228	105,330	207,131	787,099
1895	877	19,522	19,748	541	65,477	242	125,106	231,513	879,748
Totals	22,481	99,468	165,169	2,133	166,055	618	230,436	686,361	2,608,172

Note.—The gold is officially valued at £3 16*s.* per oz.

Other Metals.—In the Champion Bay district both lead and copper ores have been found in gneissic rocks associated with granite, greenstone, &c., and have, in some cases, been followed to depths from the surface exceeding fifty fathoms. The general indications pointing to the presence of a lode are the occurrence of dykes of diorite or felsite, by which the metamorphic rocks have been fissured and

[1] *The Mining Journal*, Feb. 22nd, 1896.

faulted, accompanied by masses of quartz and outcrops of pulverulent gossans. It is only at certain points, however, along the course of a lode that the veinstone reaches the surface, as a covering of soil frequently hides the rocks from view, and, generally speaking, lodes have not been prospected for, except where fragments of ore had been previously picked up on the surface. According to Mr. H. Y. L. Brown, whose report was published in 1873, ten mines had, previous to that date, been opened in this district for copper and lead, but of these only two, the Geraldine and the Oakajee, were then in operation.[1]

The chief cause of the abandonment of many of these mines was want of capital and unskilful working. From a consideration, however, of the numerous outcrops of ore at the surface, the number and size of the veins met with, and the amount of ore raised at very moderate depths, he is inclined to believe that this district affords an advantageous field for the judicious employment of capital.

The following information with regard to the depth of the lowest workings, and the quantity of ore raised, was all that Mr. Brown was enabled to gather from authentic sources:—

Name of mine.	Deepest level.	Ore in Tons.		Date.	Value at Swansea.
		Lead.	Copper.		
	Feet.				£
Huel Fortune .	300	2,475	985	1862 to 1868	
Geraldine . . .	320	1,634	—	Nov. 1869 to Dec. 1870	
Tanganooka . .	108	—	458	—	5,881
Gwalla	200	—	901	—	16,573
Wanerenooka .	180	—	—		
Gelira	100	—	300		

The total amount of lead ore exported from 1860 to 1865 was 1,363 tons. The amount of copper ore exported during the same period was 4,500 tons. In the month of April, 1881, seven lead mines were working in the Victoria district of Western Australia, the production for the year previous having been 1,430 tons of ore, valued at £10,579. There was also one copper mine in operation which, during the same year, yielded one ton of copper ore, valued

[1] *General Report on a Geological Exploration of that portion of the Colony of Western Australia lying southward of the Murchison River, and westward of Esperance Bay*, Perth, 1873.

at £15. Up to the end of 1893 the total production of lead ore is given as 34,000 tons, worth £169,000, and of copper ore as 8,530 tons, worth £144,000. In 1894 there were 822 tons of copper ore worth £8,220 produced. Tin ore has been discovered in comparatively recent times in the district of Greenbushes, about 120 miles south of Perth, the capital. Alluvial tin alone has been worked so far; its production to the end of 1892 was 827 tons, valued at £41,350. In 1893 it was 228 tons, valued at £11,400, and in 1894 it was 390 tons, valued at £15,274. The value of the total mineral production of West Australia in 1894 was accordingly £811,078.

TASMANIA.

In addition to coal, anthracite, and iron ores, Tasmania produces gold, silver, tin and bismuth, besides which galena and copper ores have, in limited quantities, been found in various parts of the island. Coal and iron ores are especially abundant, a large deposit of the latter at Ilfracombe, eight miles from the River Tamar, being described as yielding a brown hæmatite of exceptionally good quality. The mineral resources of the colony were for many years somewhat neglected, but it is now divided into six mining districts and a Department of Mines has been established. Mining enterprise in Tasmania received a great impetus at the end of 1872, by the discovery of extensive deposits of tin ore at Mount Bischoff, in the north-west portion of the island. Tin has since been found distributed over a considerable extent of territory, near the north-east corner of Tasmania, and has now become one of its most important productions.

GOLD.—Gold is obtained both from recent alluviums and from quartz reefs; auriferous Tertiary drifts, believed to be of Pliocene age, also occur, but hitherto they have not been very extensively worked, although batteries have been erected for the treatment of cement.

Reef gold [1] is found more or less in all the districts where older Palæozoic, especially Silurian, rocks occur; the Beaconsfield, Lefroy, Matthina, Mount Victoria, Mount Horror and Gladstone gold-fields, besides others, lie upon rocks belonging to this period. The Middlesex and Bell Mount fields appear, however, to be Upper Silurian. At the Lisle and Golconda fields, gold occurs in

[1] Much of the following information is taken from Mr. A. Montgomery's pamphlet on *The Mineral Resources of Tasmania*, 1894, p. 5, *et seq*.

veins in an intrusive granite. The following table [1] shows the relative importance of the various gold-fields :—

Production of Gold in the Various Mining Districts of Tasmania between the Years 1866 and 1890.

District.	Quantity of gold got.			Percentage of Total.
	Alluvial.	Quartz.	Total.	
	Oz.	Oz.	Oz.	
Beaconsfield	33,896	296,634	330,530	56·15
Lefroy and Back Creek	9,378	85,093	94,471	16·05
Lisle	74,760	—	74,760	12·70
Fingal, Mangana, and Matthina	9,261	29,088	38,349	6·52
West Coast	26,907	3,180	30,087	5·11
Mount Victoria	—	10,031	10,031	1·71
Denison, Golconda	535	3,242	3,777	0·64
Other localities	4,374	2,246	6,620	1·12
Totals	159,111	429,514	588,625	100·00

The Beaconsfield gold-field is in the county of Devon; the shallow alluvial has been almost exhausted, but the existence of a deep lead, 270 feet below sea-level, has been proved; it seems to be of Miocene age.

The principal mine in the gold-field is owned by the Tasmanian Gold Mining and Quartz Crushing Company, Registered. From the date of its discovery in 1877 up to 1894 there have been 246,886 tons of quartz crushed for a yield of 314,987 ounces, worth £1,131,829, the average yield being thus 1 oz. 5 dwt. 12 gr. of gold to the ton. The main shaft is 730 feet deep, and the only difficulty seems to be that a large amount of water has to be contended against. During six months' work in 1894 a total of 4,032 tons were crushed, yielding 8,755 ounces of gold together with a quantity of auriferous concentrates not yet treated; as this yield is over 2 oz. 3 dwt., it would seem that this mine is certainly not getting poorer in depth.

At the Lefroy field, in the county of Dorset, a number of parallel reefs, running about east and west, are being worked: some of these have yielded very well, but have rather fallen off recently. In the Lisle fields most of the alluvial has been worked out, though some high lying terraces, comparatively poor, still remain, which would pay well to "hydraulic," if water could be

[1] *Op. cit.* p. 5.

brought on to them. No reefs of sufficient importance to account for the amount of rich alluvial got here have yet been discovered; it is, however, noteworthy that the bed rock consists of the same granite as that in which the Golconda gold-quartz reefs occur.

The basin of the King River has yielded a good deal of alluvial gold, some of which has possibly been derived from deposits such as that at Mount Lyell, to be presently described. The heaviest nugget yet found in the colony, namely, 243 ounces, was found in the Rocky River in the year 1883.

The total[1] output of gold in Tasmania since the commencement of mining operations to the end of 1894 is given as 763,714 ounces, worth £2,908,512.

The following table[2] shows the production of reef and alluvial gold in the colony since 1880:—

Table showing the Production of Reef and Alluvial Gold in Tasmania during the Years 1880 to 1894.

Year.	Reef Gold.	Alluvial Gold.	Total Gold.	
			Quantity.	Value.
	Oz.	Oz.	Oz.	£
1880	34,345	18,250	52,595	201,297
1881	45,776	10,917	56,693	216,901
1882	36,215	12,907	49,122	187,337
1883	36,672	9,906	46,578	176,442
1884	30,540	11,800	42,340	160,404
1885	33,266	7,975	41,241	155,309
1886	25,004	6,011	31,015	117,250
1887	33,427	9,182	42,609	158,533
1888	34,156	5,455	39,611	147,154
1889	33,069[3]	?	32,333[3]	119,703
1890	17,829	2,681	20,510	75,888
1891	33,659	5,130	38,789	145,459
1892	34,386	7,992	42,378	158,917
1893	30,163	7,524	37,687	141,326
1894	52,239	5,634	57,873	217,024

The output for 1895 is given as 59,964 ounces.

Silver.—About the year 1885 a number of valuable silver deposits were discovered, and soon afterwards were opened up in what is generally spoken of as the Zeehan and Dundas districts;[4]

[1] *Op. cit.* p. 10.

[2] '*Report of the Secretary for Mines for* 1894–5,' p. 11.

[3] Thus in the original. Numerous discrepancies unfortunately occur in all the Tasmanian statistics.—H. L.

[4] A. Montgomery, *The Mineral Resources of Tasmania*, p. 11.

the neighbouring fields of Heazlewood and Waratak may be considered with these, as their structure is essentially similar. The Zeehan and Dundas fields[1] consist, geologically speaking, of a complicated series of ancient slates, sandstones, limestones, &c., much folded, contorted, and broken through by igneous intrusions of various ages. Interstratified amongst these rocks are beds of volcanic materials,[2] ancient lava flows and ash deposits, that are known locally as *white country*, and which may fairly be classed as rhyolite and rhyolite-tuff; their exact relations to the surrounding rocks are by no means clear. The sedimentary rocks seem to be Upper Silurian or Devonian in age; they strike generally N.N.W.—S.S.E., and dip in varying directions, forming probably an anticlinal ridge in the Zeehan field; the Dundas rocks seem to be rather older and dip at high angles, forming also a saddle between Mount Dundas and Mount Reid. The igneous rocks are granite, serpentine and diabase, the latter being of very small importance. Dykes of quartz porphyry, doubtless connected with the main granite mass, penetrate the slates in several places. In this district, as in other parts of Tasmania, tin ore occurs in connection with the granite, but its occurrence seems not to be connected with the silver-bearing lodes. The serpentine seems, however, to have a close connection with the silver deposits, many of which are enclosed in it. The serpentine appears to be an altered dolerite or gabbro; it generally contains magnetite and occasionally chromite, and at Heazlewood also zaratite. When lodes carrying galena pass through the serpentine, their gossans generally carry a good deal of crocoisite, the chromic acid of which is probably derived from the serpentine.

The Zeehan and Dundas fields are traversed by two sets of lodes, one striking between N.W. and N.N.W., and the other between N.N.E. and N.E. Their relations to each other are not yet known, but the vein-stuff in both groups seems to be similar, and both seem to be fissure veins. The gangue is chiefly spathic ore, sometimes with carbonate of manganese, quartz and more or less decomposed slate; the metallic minerals are galena, fahlore, blende, iron and copper pyrites, and other sulphides, the two first-named carrying the bulk of the silver. The vein contents are often banded, or at times brecciated in structure. The pay-ore seems to be concentrated in shoots that are rarely extensive. The

[1] '*Report of the Secretary of Mines*,' 1893, *Special Report on the Mineral Fields of the County of Montagu*, by Mr. A. Montgomery, page 1.

[2] Do., do., 1894, p. xxxviii.

gossans consist largely of oxides of iron and manganese, with oxidised compounds of the other metals, and are usually very poor in both lead and silver, and often continue poor down to the level of the unoxidised ore, which is generally well below water-level, though sometimes a rich zone carrying chloride of silver has been met with above the undecomposed ore. The veins are generally from two to six feet in width, and the wider the vein the more complete does the conversion of the ore into gossan appear to be. It is noteworthy that the rich parts of the veins seem to be practically confined to the beds of *white country*. In Dundas the best deposits seem to be contact deposits between serpentine and the stratified rocks.

Besides the fissure veins, there appears to be a tendency to form irregular deposits in some of the calcareous strata. The ore produced by concentration is fairly rich, averaging about 64 per cent. of lead and 65 ounces of silver to the ton, although parcels assaying over 100 ounces are not uncommon.

The leading mine on the Zeehan field is the Western,[1] which up to March, 1894, had produced 6,903 tons of ore, worth £80,941, the main shaft being down to a depth of 275 feet at that date. The Silver Queen mine has produced over 6,000 tons of ore, carrying over half a million ounces of silver. At Dundas, the Maestries Broken Hill and Comet mines are the most important. The following is given as the approximate exportation of silver ore from this district:—[2]

1889	200 tons
1890	500 ,,
1891	2,000 ,,
1892	7,800 ,,
1893	13,400 ,,

The Heazlewood Mine at Heazlewood, and the Silver Cliff Mine at Waratah have also turned out a great deal of rich ore.

There are numerous other districts in the colony where silver ores occur, mostly as argentiferous galena. On the Whyte River a vein of silver ore occurs at the contact of serpentinous dolerite and metamorphic sandstone, very much like some of the occurrences on the Dundas field.

Including the argentiferous copper ore produced at Mount

[1] *The Mineral Resources of Tasmania*, p. 12.

[2] '*Report of the Secretary of Mines*, 1893,' p. 6.

Lyell, the following is given as the output of silver ores in this colony during recent years:—[1]

PRODUCTION OF SILVER ORE IN TASMANIA.

Year.	Ore produced.	Value.
	Statute tons.	£
1888	417	5,838
1889	415	7,044
1890	2,053	26,487
1891	4,810	52,284
1892	9,326	45,502
1893	14,302	198,610
1894	27,263	327,152
Totals	58,586	662,917

COPPER.—Copper is known to occur in various places, but the chief deposits are those situated in the West Coast range, the best known of which is at Mount Lyell. This mine was discovered in 1886, and was worked up till 1890 as a gold mine, the ore[2] consisting of dense dark hæmatite and friable limonite, both carrying gold, and the latter being especially rich, averaging between 20 and 25 dwt. of gold, and from 20 to 25 oz. of silver to the ton. It was soon found that this was merely the gossan of a huge mass of pyrites, quite comparable with those of the Huelva district. Nothing is known as yet about the geology of the district, or whether this deposit occurs in connection with igneous rocks, as has so often been seen to be the case in other countries. As far as known, it is a mass of nearly pure massive pyrites, at least 300 feet thick and 800 feet long, lying in ribs parallel to the walls of the deposit and to the stratification of the enclosing country rocks. It seems to contain on an average about 4½ per cent. of copper, 2 oz. of silver, and 3 dwt. of gold to the ton, or a value per ton of about £2 19*s.* On one wall there is in the deposit a vein of quartz carrying fahlore and other sulphide ores, very rich in silver, which is present to the amount of between 300 and 6,000 ounces to the ton. Up to the end of June, 1894,[3] the ore got from this vein amounted to 473

[1] *The Mineral Resources of Tasmania*, p. 14.

[2] '*Report of the Secretary of Mines for* 1893': *Special Report on the Mount Lyell Mine*, p. 1.

[3] *The Mineral Resources of Tasmania*, p. 15.

tons, containing 571,003 ounces of silver and 112 tons of copper. Up to the end of 1894 the production of copper ore was 930 tons, and its value, excluding that of its gold and silver contents, was about £8,000. This mine has recently (1896) been thoroughly examined by E. D. Peters, whose opinion of it is highly favourable, and smelting plant, in accordance with his advice, is being erected. Other similar deposits appear to exist in the neighbourhood.

Tin.—Tin occurs very widely distributed in Tasmania in connection with granitic rocks, in lodes or veins, in stockworks, and in ancient and recent alluvials. Mount Bischoff, where discoveries of tin ore were first made, is situated in the north-western portion of the island, and is distant, by the present route, fifty-four miles from the port at which the ore is shipped. Its vicinity, generally, is covered with thick forests of myrtle, while the summit of the mountain, where the tin principally occurs, is so densely shrouded by an almost impenetrable jungle that even an approximate estimate of the area of the stanniferous ground becomes somewhat difficult.

According to Mr. S. H. Wintle,[1] Mount Bischoff has an altitude of about 3,500 feet above the sea, and is but little more than 1,000 feet above the surrounding basaltic table-land, the ascent from the coast being somewhat gradual. The rock consists of an eruptive eurite-porphyry, which forms a crescent-shaped ridge at the summit, of which the extremities are not more than a quarter of a mile apart, the intermediate space thus forming a horseshoe-shaped basin-like depression. It is here that the richest deposits of tin ore occur. This basin looks towards the south, and presents a natural outlet to the surrounding table-land, while the northern and western slopes are exceedingly steep, forming, on an average, an angle of 35° with the horizon. The porphyry, which is the chief matrix of the tin ore, has burst through transition strata reposing on the slopes of the mountain, displacing, contorting, and folding them in a most fantastic manner. The dykes appear to be of three kinds, eurite, quartz-porphyry, and topaz-porphyry,[2] the latter being the rock with which the ore deposits seem more especially to be connected. These strata chiefly consist of clay slate, sandstone, and other quartzose rocks, the former being frequently charged with iron pyrites and stannite.

[1] "Stanniferous Deposits of Tasmania," *Trans. Roy. Soc. of New South Wales*, ix. 1875, p. 87.

[2] H. W. F. Kayser, Mount Bischoff. *Australasian Association for the Advancement of Science*, January 8, 1892.

The tin ore (cassiterite) traverses the porphyry in strings and lodes, the breaking up of which, subsequent to the decomposition and disintegration of the surrounding porphyry, has probably been the cause of an accumulation of tinstone on the slopes of the mountain in the form of a talus. It was this stream tin that first drew the attention of prospectors, and it was only when it was being worked that the deposits in solid rock were discovered. The ore is not equally distributed over the surface, but is generally found accumulated in patches of limited extent. In illustration of this fact it may be mentioned that on one section 240 tons of tin ore were taken from an area of wash-dirt only sixty-six feet square, while at a distance of twenty yards on either side of the cutting scarcely a trace of tinstone could be found. Some of the masses of ore taken from the dirt on this claim weighed as much as six cwts., and not a few of them were almost entirely free from matrix. It appears somewhat remarkable that only one well-defined lode had, up to the beginning of 1875, been laid bare in this district, although surface mining had then been in active operation for more than two years. Other so-called lodes are now known, but the true character of the deposit is far from being understood.

Although the porphyry is the chief source of the ore, there are also rich deposits consisting of tin ore and hydrated oxide of iron, in which a face has been opened up to a depth of 30 feet. Ascending the slope of the basin in the direction of the top of the mountain, the tin ore, iron ore and sand assume a cemented condition, and finally, at the summit, appear in cliff-like masses of conglomerate composed of a mixture of oxide of tin, iron oxide and silica, sufficiently hard to require blasting. So rich in tinstone is this formation that blocks, weighing several cwts., of nearly pure tin oxide may sometimes be broken from it. This deposit, which is known as the North Lode, can be traced for a distance of about half a mile. Small grains of native copper have been found associated with the ferruginous tin ore, while rich argentiferous galena and sulphides of antimony and zinc occur in adjoining claims. The galena is accompanied by a gangue of fluor spar and carbonate of iron, but the only veinstone associated with stibnite and blende is fluor spar.

That Mount Bischoff has been subjected to much dislocation is evident from an extensive line of fault running north and south, by which the whole of the eastern side of the mountain side has been depressed, thus producing a line of vertical cliffs in some places more than 100 feet in height, which affords a fine section both of the intrusive porphyry and of the contorted sedimentary strata. It is said to rain at Mount Bischoff three days out of every four, the result being that all vegetation, as well as the numerous boulders on the surface of the ground, are thickly covered with moss. The gradual decay of these mosses has produced a stratum of peat often five feet in thickness, which constitutes the only "stripping" of the miner, as the tin ground lies immediately beneath it. The mine was discovered in 1871,[1] and work was started towards the end of 1873; by the end of June, 1891, the ore produced amounted to nearly 37,088 tons, worth £2,300,000, almost exactly one-half of which sum was clear profit.

Mount Ramsay, which is situated at a distance of about ten miles from Mount Bischoff, attains an altitude of over 4,000 feet, and is essentially composed of a coarse-grained schorlaceous granite which occasionally passes into a fine-grained rock. This granite rises in the form of three lofty peaks, and, unlike Mount Bischoff, the older Palæozoic strata are only to be seen mantling around its base. The tin which is found here does not occur in such large quantities as at the last-named locality, but Mount Ramsay is well known for a large and rich deposit of bismuth, which when first discovered was mistaken by the miners for tin in a native state. Later investigations seem to show that the bismuth occurs here as native bismuth disseminated in a hornblendic rock.

Tin ore also occurs at Wombat Hill, about midway between Mount Bischoff and Mount Ramsay, and at Mount Housetop, twenty miles from the north-west coast of the island, where, in both instances, it is found in granite. The cassiterite is sometimes associated with zircon and pleonaste. On the east coast a rich deposit of stream tin occurs near the source of a small river known as the Golden Fleece, and the stanniferous district extends in a south-easterly direction as far as Falmouth and the Mount Nicholas Range. More recent discoveries show that a tin-bearing country exists for a great distance towards the north-west, as for instance at Boobyalla, Mount Cameron, Mount Horror, and in the Ringarooma district.

The last-named district has been most extensively worked, the Ringarooma and all its tributaries being rich in alluvial tin deposits; although many of these have been worked out to a great extent, the existence of a deep lead, following approximately the present course of the valley, and overlain by basalt, has been proved, and branches of it have been worked.

[1] H. W. F. Kayser, *op. cit.* p. 12.

This deposit was probably of Miocene age, whilst the shallower deposits range from this period up to recent times. The Georges River is also rich in alluvial tin deposits, and others are known at Mount Heemskirk, Bell Mount, North Dundas, and many other places.

Stockworks of tin are also known in the colony, again in granite, which seems to be everywhere the matrix of the tinstone, although at Mount Lyell tin ore is found in Silurian strata. The tin deposits of Tasmania have been the greatest source of its mineral wealth, the value of the tin ore raised exceeding that of all the other minerals together. Tasmania takes rank as the third largest tin-producer in the world. The following table[1] shows the production of tin since it was first exported, all the ore being calculated as metal, upon well ascertained percentages :—

TABLE SHOWING THE PRODUCTION OF TIN IN TASMANIA FROM THE COMMENCEMENT IN 1873 TO THE END OF 1894.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Tons.	£		Tons.	£
1873	3	220	1884	3,698	301,423
1874	100	7,318	1885	4,242	357,587
1875	366	31,325	1886	3,776	363,364
1876	1,453	99,605	1887	3,606	407,857
1877	4,760	296,941	1888	3,775	426,326
1878	5,369	316,311	1889	3,786	345,407
1879	4,378	303,203	1890	3,213	296,761
1880	3,953	341,736	1891	3,277	293,170
1881	4,123	375,775	1892	3,195	290,794
1882	3,647	361,046	1893	3,129	260,219
1883	4,100	376,446	1894	3,145	269,600
		Totals		71,094	6,122,434

OTHER METALS.—A lode of bismuth, then stated to be one of the richest in the world, was discovered some years since at Mount Ramsay, and another containing stibnite was met with in the Waratah Company's claim. Argentiferous galena has been found at the Penguin, and also in the neighbourhood of Mounts Roland and Claude, while copper ore occurs near Campbelltown. About 1,500 tons of ironstone were raised during the year 1881.

[1] *The Mineral Resources of Tasmania*, p. 22.

The production of Tasmania in 1894 is given as follows in an official return:—

	Weight.	Value.
Gold . . .	58,059 ounces . .	£225,485
Silver ore . .	21,064 tons . .	293,043
Copper ore. .	125 „ . .	5,000
Tin ore . .	4,284 „ . .	156,865
Total value of metallic minerals		£680,393

New Zealand.

A considerable proportion of the population of New Zealand is occupied in gold mining, which, during the last thirty years, has been one of the most important industries of the colony. Ores of various other metals, such as copper, silver, lead and mercury, although known to occur in various localities, have not hitherto been extensively worked.

Gold.—According to a memoir by Dr. A. Soetbeer[1] about 1,000 oz. of gold were obtained at Cape Coromandel, upon the eastern side of the North Island, in 1852, after which the workings were virtually abandoned. Four years subsequently gold mining was commenced in the province of Otago, in the South Island, and in 1861 a large increase in the gold production took place consequent on the discovery of rich deposits in the Tuapeka River, and and at the Thames gold-fields. The North Island, although containing a large number of known quartz reefs, has produced less gold than the South Island, which is much richer in alluvial deposits. Its most important districts stretch on the western slope of the mountains, from Otago on the south, through the Westland gold-fields to those of North-west Nelson on the north.

The auriferous drifts of New Zealand occur in three distinct forms:—Firstly, as modern alluvium in the beds of streams and rivers; secondly, as more ancient deposits often occupying the sides of valleys; thirdly, as sands upon the seashore, where, by the constant action of the waves, a process of continuous concentration is in progress. The deposits belonging to the first-class are of the ordinary kind, and exhibit no peculiarities to render a special description necessary. Deposits of the second class are sometimes

[1] "Edelmetall-Produktion und Werthverhältniss zwischen Gold und Silber," published as an extra number of *Petermann's Mittheilungen*, 1879.

of great thickness, many of them being regarded as belonging to the lowest Tertiary deposits of the colony. They are frequently so consolidated as to form a compact cement, and are then stamped and treated in the same way as gold quartz. When not so cemented, they are often worked by the Californian process of hydraulic mining, for which facilities are afforded by the Government, which has, in some cases, brought in the necessary water, which is supplied to the miners at a fixed charge.

Some remarkable deposits of auriferous cements are worked at the Blue Spur, in the Otago district. The Blue Spur cements are enclosed in a trough, or more correctly, a basin, since, in addition to the bed-rock on which they rest as in a trough, the schists to the north-west and south-east rise in the form of hills which have a greater elevation than is at present assumed by the cements themselves. The bed-rock on the north-east side of the basin is very steep, while on the opposite one it is more shelving; the total thickness of the cements is regarded by the officers of the Geological Survey as being at least 300 feet.

An enormous quantity of this Spur has been worked away, so that what remains has been cut into deep gutters, and, where sluicing or other claims have been for a long time in operation, large masses of the hill have been removed. The Spur, therefore, which must formerly have possessed a configuration similar to that of the surrounding country, now presents a series of lofty pinnacles and steep cañons, bearing testimony to the large amount of work which has been done.[1] As a rule the rivers of New Zealand have extensively eroded their beds since the formation of the older alluvium, so that the deep leads, which often in other countries can only be reached with great trouble and expense, are here exposed in the declivities of valleys. No deep leads appear to be worked under a capping of basalt, as is the case in Australia and California, and the extension of the gold districts among the more recent volcanic rocks appears to be comparatively small. In 1894, practically the whole of the alluvial gold, which formed about 60 per cent. of the total production, was got in Middle Island, where, as previously pointed out (see page 24), the various deposits belong to widely different geological epochs.

The auriferous sands on the seashore, forming the third class of deposit, are worked by persons known as "beach combers," who wash them by the aid of fresh water brought through a canvas hose-pipe, upon movable sluices, called "beach boxes," one end of

[1] *Reports of Geological Explorations during* 1878-79, Wellington, 1879, p. 49.

which is mounted on wheels for convenience of transport. Beaches are often unworkable for months together, since gold in remunerative quantities is only found upon them after the occurrence of high winds and heavy seas. Of recent years, however, dredging machines have been employed both on these beaches and on some of the rivers, with very encouraging results.

According to Ulrich the rocks in which auriferous reefs occur, or in which gold has been found in its natural matrix, in the province of Otago, excepting in the neighbourhood of Portobello, consist throughout either of argillaceous mica schists or of phyllite, changing towards the west into true mica schist with subordinate bands of chloritic schist or chloritic mica schist.[1] In most cases both the phyllite and mica schist, which are probably of Silurian age, but more especially the latter, are rich in interlaminations of quartz, which are sometimes less than one-fourth of an inch in thickness, but occasionally attain a width of three or more feet. These generally lenticular masses, which have no regularity or persistence either in strike or in dip, frequently contain gold, and there can be no doubt that the gold in the drifts of the province is in some measure due to their denudation and disintegration.

Some of the reefs are, however, true lodes, with well-defined walls having clay selvages, and crossing the country rock both in strike and dip. Others are composed of a mixture of quartz and mullock, and are known as *quartz mullock reefs*; these are usually so soft that they can be worked without the aid of gunpowder, and the quartz, which does not appear to form a large percentage of the mass, occurs only in the shape of coarse sand and small and slightly rounded fragments. Whether the quartz originally formed interlaminations in the mullock or occurred in veins is uncertain, but Mr. Ulrich considers that a kind of banded structure which is observable on the line of dip is in favour of the latter hypothesis. The reefs of Arrow and Skipper's Creeks are true lodes, some of which are twenty feet in thickness, cutting through the country both in strike and dip, and showing more or less distinct walls with clay casings. In point of composition and structure they, however, approach far more nearly to mullock reefs than to quartz reefs; they in fact represent fissures partly filled with *débris* from the country rock, mixed with interlaminated quartz, of which there are veins and branches of varying dimensions. *Layer lodes* follow the strike and dip of the country rock, having throughout

[1] F. W. Hutton and G. H. F. Ulrich, *Report on the Geology and Gold-fields of Otago*, Dunedin, 1875, p. 156.

for their foot wall one and the same bed, while the hanging wall is generally irregular, and frequently traversed by veins and branches of quartz. On account of this mode of relation to the country rock they are subject to all its changes of strike and dip, and, when these are great, they are liable to frequent changes in thickness, and are regarded as being the least promising form of reef.

The so-called Peninsula Quartz Reefs at Portobello are not in reality quartz reefs at all, but merely impregnations of finely divided gold enclosed in siliceous deposits in trachytic rocks. This occurrence of gold in a trachytic matrix is, however, not without its alliances, since the grayish-white trachyte of Portobello bears a certain resemblance to the gold-bearing trachytic tufa of the Thames gold-field in the North Island, although in the latter locality the gold is found in distinct veins and bunches of genuine quartz, and does not occur disseminated through the mass of the rock as in the other case. The rock in which the *quartz reefs* of the Thames gold-field are found is a massive formation of tufa passing on the one hand into a compact trachyte, and on the other into a coarse brecciated rock, consisting of angular fragments embedded in a tufaceous cement. The age of this formation is somewhat uncertain, but at Tapu Creek it rests upon black slate, and at Coromandel it is overlain by brown coal, which is again overlain, unconformably, by a recent volcanic formation referred to the Eocene period. It is therefore probable that the tufas in which the auriferous reefs are found belong to some part of the Cretaceous period.

From some cause, not yet ascertained, this tufaceous formation has become decomposed in a very irregular manner, and to great depths, the undecomposed rock forming hard ridges separated from one another by belts of softened material extending to many hundred feet below the sea level. In these latter bands alone productive quartz veins have been found, and, so far as is at present known, they either pinch out or become unremunerative on entering the undecomposed rock.[1] Some of the reefs in this gold-field have been worked to a depth of more than 100 fathoms below sea level.

In the year 1881, the quartz crushed in New Zealand amounted to 65,712 tons, yielding 84,792 oz. of gold, or 1 oz. 5 dwt. 19 gr. per ton.

[1] *Reports of Geological Explorations during* 1878–79, Wellington, 1879, p. 22.

The following table shows the returns of the various quartz mining districts of New Zealand for the year ending 31st of March, 1895:—

Name of district.	Quartz crushed and tailings treated.	Total quantity of gold got.	Approximate value.
	Tons.	Oz.	£
Coromandel	15,451	22,632	62,996
Thames	48,464	22,810	59,340
Ohinemuri	51,058	110,628	137,699
Piako	1,121	628	1,711
Marlborough	25	14	54·6
Nelson	3,554	657	2,562·3
West Coast	38,370	18,360	71,604
Otago	13,390	5,713½	22,282·6
Totals	171,433	181,442½	358,249·5

As is shown by the above table, much of the New Zealand gold is low grade and highly argentiferous, so much so that some of the bullion produced is worth only £1 per ounce. At the same time, it must be noted that over 52 per cent. of this gold was got by cyanide extraction, which produces a lower grade bullion than does amalgamation. The value of the quartz is seen to average only about £2 per ton. It may also be mentioned that the total value of gold entered for exportation was £889,545, out of which only £373,676 was obtained from quartz and the rest from clastic deposits. The most important mine in the colony in 1894 was the Waihi, in the Ohinemuri district, which had been opened to a depth of 240 feet, where three parallel lodes, or branches perhaps of one and the same lode, have been cut, the widths varying from six feet to thirteen feet. During that year 24,864 tons of stone had been crushed, yielding 55,437·5 ounces of bullion worth £82,524; the total expenditure for the year was £40,977. In 1894 there were 2,191 men engaged in quartz mining in New Zealand. It is worth noting that the cyanide process of gold extraction has been found to be especially well adapted to the New Zealand ores; the Sylvia Company[1] at Tararu has used it with marked success.

The following table[2] shows the weight and value of the gold exported from New Zealand from the beginning of 1857 to the end of the year 1894:—

[1] Dr. A. Scheidel, *The Cyanide Process*, Sacramento, 1894, p. 79.

[2] *Papers and Reports relating to Minerals and Mining*, N.Z. 1895.

Table showing the Weight and Value of Gold, the Produce of the Colony, Exported from New Zealand during the Years 1857 to 1894.

Year.	Weight.	Value.	Year.	Weight.	Value.
	Oz.	£		Oz.	£
1857	10,437	40,422	1876	322,016	1,284,328
1858	13,534	52,464	1877	371,685	1,496,080
1859	7,336	28,427	1878	310,486	1,240,079
1860	4,538	17,585	1879	287,464	1,148,108
1861	194,031	751,873	1880	305,248	1,227,252
1862	410,862	1,591,389	1881	270,561	1,080,790
1863	628,450	2,431,723	1882	251,204	1,002,720
1864	480,171	1,856,837	1883	248,374	993,352
1865	574,574	2,226,474	1884	229,946	921,797
1886	735,376	2,844,517	1885	237,371	948,615
1867	686,905	2,698,862	1886	227,079	903,569
1868	637,474	2,504,326	1887	203,869	811,100
1869	614,281	2,362,995	1888	201,219	801,066
1870	544,880	2,157,585	1889	203,211	808,549
1871	730,029	2,787,520	1890	193,193	773,438
1872	445,370	1,731,261	1891	251,996	1,007,488
1873	505,337	1,987,425	1892	238,079	954,744
1874	376,388	1,505,331	1893	226,811	913,138
1875	355,322	1,407,770	1894	221,615	887,839
Totals				12,756,722	50,188,838

The output for 1895 is given as 293,491 ounces.

Other Metals.—Silver ores and argentiferous lead ores are sometimes met with in the gold-bearing reefs of Coromandel and the Thames, but no distinct lode of either of these minerals has yet been discovered. Silver is obtained only as an alloy with gold in the bullion produced; the amount in 1894 was 54,117 ounces, valued at £6,697. Copper mining was for some years conducted on a somewhat extensive scale at Kawau and Great Barrier Islands, but although a considerable amount of copper ore was obtained, the mines were not financially successful. A small quantity of copper ore was raised from a vein on D'Urville Island, but the workings are by no means extensive, and the yield of copper ore has hitherto been but small. Not more than 350 tons have been produced in any one year, and the total production for forty years up to 1894 was only 1,400 tons; none at all is returned for the last five years or more. Specimens of cassiterite have from time to time been found in the Thames gold-fields.

In the Westland District, South Island, eight miles from Greymouth, in the hills north of the Grey River, where there were formerly extensive sluice diggings, is a quartz reef which for a long time attracted little or no attention. In 1878, however, some blocks of stibnite found in the alluvium were discovered to contain a considerable proportion of gold. This lode, which is known as "Langdon's Reef," is about 600 feet above the river, and appears as a solid ledge of white quartz from three to eleven feet in thickness, encased in compact slate. The quartz of this lode contains traces of antimony, and specimens taken from portions of the vein traversed by blue strings of stibnite yielded gold at the rate of 84 oz. per ton. Following up the same creek, at an altitude of 400 feet above Langdon's Reef, the lode from which the auriferous stibnite was originally derived has been discovered. It has a total width of nine feet, and is divided into five distinct bands, three of which consist of a mixture of quartz and stibnite; one, two feet in width, mainly consists of compact stibnite, while the fifth is composed of about one foot eight inches of brecciated slate. Specimens from this lode forwarded to Dr. Hector for assay yielded gold 84 oz. and silver 36 oz. per ton, but the highest results obtained from specimens collected by Dr. Hector himself yielded gold at the rate of only 36 oz. per ton.[1]

Antimony ore was produced in 1894 to the amount of 44 tons.

Chrome iron ore has been mined from time to time, but none has been shipped since 1866.

Manganese ore has been got in fluctuating quantities during the last fifteen years; in 1894 the yield was 534 tons, valued at £1,156.

Iron ores in the form of limonite and black iron sands occur in various localities, and have been mined experimentally. A project is now (1896) on foot for smelting these latter in the blast furnace by a special method.

Cinnabar has been found in several places in alluvial drifts, especially at Waipori. At Ohaeawai[2] a lode, which seems to consist of siliceous sinter carrying cinnabar, has been traced and is being tested. Its course is about north and south, dipping about 45° to the west. The formation is described as a green marly sand, full of water, so that sinking is a matter of difficulty. In sinking a vertical shaft to cut the lode, springs of water as hot as 200° F., and gases, amongst which were sulphuretted hydrogen and carbonic acid, were met with. The mineral appears to consist of iron pyrites with cinnabar, the sintered outcrop carrying from six to eighteen per cent. of metallic mercury. Pockets of native sulphur have been met with, and thermal springs and solfataric emanations

[1] *Reports of Geological Explorations*, 1878-79, p. 19.

[2] *Papers and Reports relating to Minerals and Mining*, N.Z. 1895, p. 257.

seem to abound. The vein seems to be near the line of intersection of the above-mentioned marls by a hard basaltic rock. It will be noticed that the phenomena here observed are very like those recorded at Sulphur Bank, California, and at Steamboat Springs, Nevada (see page 115). The commercial value of the deposit has not yet been ascertained.

New Caledonia.

It was at one time supposed that the mineral wealth of New Caledonia would rival that of Australia and New Zealand, but hitherto these hopes have been to a large extent disappointed. Gold and copper veins are known to traverse the primitive rocks of the north part of the island, and the serpentines contain ores of iron, chromium, &c. In the year 1863 a few grains of gold were found in the alluvium of the Houébiahomme Valley, and in 1870 workings upon an auriferous quartz vein were commenced, at a place afterwards named Fern Hill, by English miners, by whom the claim was taken up. By the month of September, 1873, a mill had been erected, and 1,200 tonnes of quartz had been crushed, which yielded 4,663 oz. of gold; but, by the end of the same year, a mass of pyrites from which no gold could be extracted with the appliances available had been reached, and the mine was shortly afterwards abandoned. Since that period little or no attention appears to have been devoted to gold-mining, although it would appear improbable that this should be the only instance of the occurrence of auriferous quartz in the island.[1]

The most important ores furnished by New Caledonia appear to be those of nickel, which occurs in a mineral discovered here for the first time. This mineral, which is a silicate of magnesia containing nickel, was discovered by M. Jules Garnier, and has received the name of garnierite. It occurs in vein-like deposits in serpentine or serpentinous rocks, and would seem to be in all probability a product of segregation from these rocks; it may possibly, however, be due to the leaching action of water on the serpentine, and subsequent deposition from solution in fissures that may have been fissures of contraction. The general strike of these deposits is N.E.—S.W., about at right angles to the general trend of the serpentinous rocks.

[1] Émile Heurteau, "Les Richesses Minérales de la Nouvelle-Calédonie," *Ann. des Mines*, ix. 1876, p. 307.

The method of extracting nickel from the ordinary ores of that metal consists in concentrating it as a regulus or speiss, dissolving in acid, precipitating the nickel in the form of oxide, and reducing the precipitate with carbonaceous substances. As garnierite contains neither sulphur nor arsenic, it becomes necessary to add one of these substances to the ore in sufficient quantity to take up the nickel, and this method of treatment is, under certain circumstances, recommended by M. Garnier. As, however, the sulphur and arsenic thus added have to be again separated from the nickel, a new process has been invented.[1] This consists in smelting the silicate of nickel with iron ores in a blast furnace, with a cold blast, and at a low pressure. Under these conditions, and with a properly constituted mixture, only a portion of the iron is reduced, while the remainder passes into the slags, unaccompanied by nickel, and adds to their fusibility. In this way is produced a carbide of the two metals known as ferro-nickel, from which the nickel may be separated by a humid process. The ore is now shipped to Europe for treatment, partly to England and partly to France, where it is smelted in the départements of the Seine and of the Seine-Inférieure. The amount of metallic metal produced in France during 1894 was 1,545 tonnes, worth about £160 per tonne. The production of nickel ore, containing ten to twelve per cent. of metal, in New Caledonia was :—

In 1892	83,000 tonnes.
1893	69,130 ,,
1894	61,243 ,,

The exports for the two last years were respectively 45,613 and 40,089 tonnes, the average value being given as 70 francs (about £2 16*s.*) per tonne. The number of men engaged in nickel mining was 2,121.

Chrome iron ore, which also occurs in lenticular masses in the same serpentine, from which it may have separated as a segregation product, has been mined to some extent since 1883; in 1894 the output was 2,927 tonnes.

This same serpentine also carries deposits of highly cobaltiferous manganese ore, containing three to five per cent. of cobalt; these deposits produced in 1894 over one-third of the total cobalt output of the world, yielding 4,112 tonnes of cobalt ore, valued at 70 francs (£2 16*s.*) per tonne.[2]

[1] J. D. Hague, *Mining Industries*, Washington, 1880, p. 191.
[2] *Statistique de l'Industrie Minérale for* 1894, p. 57.

AFRICA.

The precious metals appear to be very generally distributed throughout Africa, and, so far as is at present known, form the principal portion of its mineral production. Until the discovery of gold in California and Australia the gold-fields of the Kong Mountains in Guinea were considered to be amongst the most important in the world, but since then Africa played a very subordinate part, until the Transvaal gold-fields once more brought this continent into prominence. The gold-fields of the Transvaal are numerous, but the yield obtained from them was quite insignificant until the year 1887, when they rapidly began to assume a foremost position among the great gold producers. Dr. Soetbeer estimated the amount of gold produced in the whole of Africa during the year 1875 at 96,450 oz. troy, but it was nearly thirty times this amount only twenty years later.

Copper is known to exist in large quantities in the mountains of some of the native kingdoms of Central South Africa, and one of the objects of Dr. Livingstone's last journey was to visit the celebrated copper district of Katongo, south-west of Lake Tanganyika. At the Cape of Good Hope there are some valuable copper mines, while at Bembi, near Ambriz, a thick malachite vein was formerly worked by the negroes, and afterwards leased to an English company by the Portuguese Government. Abyssinia is supposed to be rich in copper ores, and iron ores occur in many parts of Inter-tropical Africa. On the banks of the Senegal, and in various other districts, the natives smelt iron, the ore used being a rich ferruginous sandstone of modern formation. Morocco contains ores of various metals, but of the whole Mediterranean seaboard Algeria alone deserves special notice, as some of its mines are both extensively and systematically worked.

ALGERIA.

The most important ores of Algeria are those of iron, which occur in the form of magnetite, red and brown hæmatite and siderite. Argentiferous galena, copper ores containing lead and silver, ores of antimony and mercury, as well as calamine and blende, occur in this part of Africa. Manganese, nickel, cobalt and arsenic are likewise occasionally found, but always in association with ores of other metals.

IRON.—In the département of Constantine, the Mokta-el-Haddid Company works the mines of Kharézas, Bou-Hamra, and Aïn-Morkha, the last of which is connected with the port of Bône by a railway about twenty miles in length. This mine, which is more commonly known by the name of Mokta-el-Haddid, is an irregularly stratified deposit, included in mica schist, which originally formed a cliff 400 feet in height, exposed upon a bend in the outcrop where the iron ore is unusually massive. This deposit has been extensively worked as an open quarry by a succession of terraces each sixteen feet in height, of which nineteen were required to reach the top of the ore ground. The bed dips at an angle of about 30°, and its greatest thickness, measured horizontally, is somewhat more than 100 feet, but it gradually becomes flatter and diminishes in size until it is worked underground, where its thickness does not exceed twenty-eight feet. A second bed, thirteen feet in thickness, between the schistose roof of the main deposit and an overlying bed of limestone, has been discovered by boring. The ore is generally a blueish or blackish mixture of very dense hæmatite and magnetite, containing from 58 to 66 per cent. of metallic iron; a portion of it is, however, soft and brownish-red in colour, and can be readily worked without the aid of gunpowder.

In the département of Alger, spathic iron ores, and hæmatites resulting from their decomposition and peroxidation, are found in veins enclosed in Cretaceous rocks. These are for the most part associated with ores of copper and lead, which are, sometimes, the prevailing minerals.

Another class of deposits, occasionally of considerable importance, occurs in the département of Oran. These consist of hæmatites, associated with limestones, probably of Liassic age, and the ores, which vary considerably in composition, are often manganiferous, and in most cases moderately hard. Masses of totally unchanged limestone are sometimes found included in these ore bodies, whose origin M. Pouyanne attributes to the action of mineral waters.[1] Yet other deposits occur in strata of Miocene age, and are considered to have been derived from the waste of Jurassic ores. The most important mines are those of Camérata, Soumah and Beni-saf; the latter of which is situated about sixty miles west of

[1] "Note sur la Région ferrifère des Ouelhassa," *Ann. des Mines*, ix. 1876, p. 90.

Oran, and yields a soft calcareous hæmatite not unlike that of Bilbao.

The mines of Aïn-Morkha, worked by the Mokta-el-Haddid Company, have produced annually about 400,000 tonnes of iron ore, and from 1867 to 1877 yielded 3,176,500 tonnes, of the value of thirty-five millions of francs, or about £1,400,000. The production of iron ores in Algeria during the year 1880 amounted to 614,000 tonnes.

In 1894 it was as follows:—[1]

Département.	Quantity. Tonnes.	Value. £
Oran . . .	227,753	. . . 70,600
Constantine	115,627	. . . 34,900
Alger . . .	450	. . . 45
	343,830	105,545

The whole of the output from Oran is produced from the mines of the Mokta-el-Haddid Company, which also produces the whole of that from Constantine, with the exception of some 7,000 tonnes from the El M'Kimen concession.

Other Metals.[2]—In the département of Constantine, in 1876, the lead mines of Kef-Oum-Theboul, near La Calle, yielded 12,000 tonnes of galena, containing about 38 per cent. of lead and affording work lead yielding 36 oz. of silver per ton. In addition to argentiferous galena this mine produces both copper ore and blende, while the mines of Cape Cavallo in the same département yield argentiferous lead and copper ores.

In the département of Alger explorations for blende and galena have been carried on, and in the département of Oran the mine of Gar-Rouban produces small quantities of argentiferous galena.

The copper mine of Aïn-Barbar in the département of Constantine, eleven miles north-west of Bône, is worked upon several veins producing oxides and sulphides of copper, yielding from 8 to 15 per cent. of that metal, together with copper pyrites and blende.

Various mines have from time to time been to some extent worked near Cape Tenès, in the département of Alger, and have

[1] *Statistique de l'Industrie Minérale pour l'année* 1894, p. 23.

[2] L. Ville, *Situation de l'Industrie minière des départements d'Alger, d'Oran et de Constantine*, Algiers, 1874.

yielded limited amounts of copper and lead ores, but at the present time none of them appear to be in active operation.

The once celebrated copper mine of Mouzaïa, in the same département, which at one time was supposed to contain almost fabulous riches, and was the subject of much wild speculation, yielded antimonial gray copper ores only. In this locality there are several veins composed of spathose iron ore and heavy spar, containing disseminated antimonial gray copper ore, and traversing a soft marly country rock. When first discovered, the surrounding marly rocks of Cretaceous age had been to such an extent acted upon and removed by rain and other meteoric influences, that the outcrops of the veins stood from 12 to 15 feet above the surface of the adjoining ground, and could be thus traced as distinct parallel walls over a very considerable distance.

This mine, the working of which has been undertaken successively by various companies, was finally abandoned in 1865, on account of the difficulties experienced in the metallurgical treatment of its ores.

The mines of Oued-Merdja are situated on the right bank of a stream of that name, near the point of its confluence with the Oued-Chiffa, about seven miles south-east of Blidah. The concession shows several nearly parallel veins containing copper pyrites, but of these one only, namely, that nearest the point of meeting of the two streams, has been to any extent explored. The veinstone associated with yellow copper ore is principally ankerite, a triple carbonate of calcium, magnesium and iron. In the year 1866 a powerful steam pumping-engine was erected at this mine, as well as furnaces for the conversion of the poorer ores into regulus.

In the vicinity of Blidah, in the valley of the Oued-Kebir, is situated the mine bearing the latter name. This concession may almost be regarded as an extension of that of Oued-Merdja, and is traversed by nearly similar lodes, towards the development of which but little has hitherto been accomplished.

Zinc ores are raised in the département of Constantine at the mine of Hammam-Nbaïl, belonging to the Vieille Montagne Company, at that of Aïn-Arko, and at the lead and zinc mine of Oued Maziz in the département of Oran.

The antimony mines of El-Hamimat are situated at a distance of forty-three miles from Constantine, and consist of a vein containing oxide of antimony at Semsa, and an irregular deposit of stibnite at Djebel Hamimat. These mines, which on account of local disturbances remained for some time unworked, have been re-opened.

The only known deposits of cinnabar in Algeria occur in the département of Constantine in the districts of Guelma and Jemmapes; but the only mine actually at work is that of Ras-el-Ma, fifteen miles south-east of Philippeville.

The production of metalliferous minerals, other than ores of iron, during the years 1880 and 1894 was as follows:—

Production in Algeria of Metalliferous Minerals other than Iron Ores during the Years 1880 and 1894.

1880.

Description of ore.	Quantities.	Values.	
	Tonnes.	Francs.	£
Lead and Silver ore	4,066	512,655	20,506
Copper ore	9,574[1]	714,309	28,572
Zinc ore	976	42,615	1,704
Antimony ore	567	226,800	9,072
Mercury ore	200	10,000	400
Totals	15,383	1,506,379	60,254

1894.[2]

Description of ore.	Quantities.	Values.	
	Tonnes.	Francs.	£
Argentiferous galena	276	20,225	805
Blende and Calamine	29,703	816,959	32,675
Antimony ores	175	26,000	1,040
Mercury ores	866	58,008	2,320
Totals	31,020	921,192	36,840

CAPE OF GOOD HOPE.

During the last forty-five years large quantities of copper ore have been obtained from Namaqualand, Cape of Good Hope, where it appears to occur in somewhat irregular deposits, interstratified with gneiss. The following amounts of ore, containing on an

[1] Minerais complexes, equivalent to the bluestone of Anglesea, are returned in this table as copper ores.

[2] *Statistique de l'Industrie minérale pour l'année* 1894, p. 59.

average $29\frac{1}{2}$ per cent. of copper, have been obtained from these mines since they were first opened in 1852 up to the end of 1882 :—[1]

		Tons.
Raised from 1852 to end of 1862 from Springbok, Specktakel and Ookiepe mines		18,999
Raised by the Cape Copper Co. from 1862 to end of 1882, 20 years.	Ookiepe	164,025
	Specktakel	14,765
	Trial Mines	1,057
	Total	198,846

All these deposits are enclosed in gneiss, of which they appear to follow the strike and dip. That of Ookiepe, which has been the most productive, has been worked for a length of 175 fathoms, and to a depth of 105 fathoms. It, together with the enclosing rocks, is crossed by a slide, by which it has suffered a throw of 40 fathoms. Wherever it has been cut through in depth a bed of quartzite has been found immediately beneath it.

The value of the copper ores produced in Namaqualand during the year 1882 amounted to £331,546.

The two principal companies now at work here are the Cape Copper Mining Company and the Namaqua Mining Company. In 1885 the production of Namaqualand was 20,213 tons, valued at £395,675, and in 1894 it was 34,281 tons, valued at £360,573.

In the year ending April 30th, 1896, the Cape Copper Company, Limited,[2] produced as follows from their various Namaqualand mines :—

Ookiep	26,200 long tons (@ 21 cwt.), containing		19·75 % of copper
Spektakel	1,597 ,, ,, ,,		28·08 ,, ,,
Nababeep,	about 300 ,, ,, ,,	about	7 ,, ,,
Copperberg	,, 550 ,, ,, ,,	,,	11·5 ,, ,,
Ookiep East	,, 1,600 ,, ,, ,,	,,	6 ,, ,,

In their smelting works 18,487 tons of ore were treated, chiefly from the Ookiep mines, which yielded 52 per cent. of regulus. In the year ending June, 1896, the Namaqua Copper Company, Limited,[2] raised from their Tweefontein Mine at Concordia and dressed 6,672 tons (@ 21 cwt.), containing 28 per cent. of copper, and stacked 7,600 tons ready for treatment, estimated to produce a further amount of 1,840 tons of the same richness as the former. This Company shipped 5,272 tons of copper during the year.

Galena, zinc blende and manganese ore also occur in the Cape

[1] Statement furnished by Mr. R. Taylor.

[2] From *The Directors' Reports for* 1896.

Colony, and gold has been found in various places; but, in spite of repeated and strenuous efforts, nowhere in paying quantity.

The chief locality is the Knysna district, where it occurs in narrow quartz veins traversing schists; several attempts were made to work these, but without success, the total amount of gold obtained having been only some 2,000 oz. A little alluvial has also been found in this district.

A quite unique, but not payable, occurrence of gold is that at Craddock, where gold occurs associated with prehnite; these minerals seem to occur in geodes or nests in dykes of igneous rock.

In spite of its apparent poverty in metallic minerals, the Cape Colony possesses unique mineral deposits of enormous value in the shape of the diamond mines of the Kimberley district.

GOLD COAST.

As its name implies, this West African colony has long been known to be rich in gold, gold dust having formed an article of export thence long before Europeans attempted any mining operations there. The greater part of this gold was not obtained from placers, but from crushing the auriferous deposits in hard rock. These deposits are of two kinds, veins and beds. Small and unimportant patches of alluvial occur along the edges of some of the swamps with which the country abounds, and in the banks of some of the smaller streams, but no alluvial deposits of commercial importance are known. The gold district seems to occupy a belt running nearly north and south, traversed longitudinally by the river Ancobra. The quartz veins nearest the coast, which were worked at Akankoo, Cankim Bamoo, &c., are situated some fifteen to twenty miles up the river. The quartz, which seems to occur in veins of relatively short extension, and up to six feet in width, is dark blue, somewhat vitreous, in places very much impregnated with schorl, so much so as almost to pass into a kind of schorl rock; the gold is coarse, crystalline, and very free, the associated minerals being chiefly titaniferous iron ore, and small quantities of zinc blende, galena, iron and copper pyrites. The average yield may be called about 6 dwt. to the ton. The country rock is a soft clay rock, possibly laterite, or possibly a decomposition product of clay shales; no stratification could be determined, and the relation of the reef to the country rock is therefore unknown. After a protracted trial these reefs were abandoned as not payable; some thousands of ounces of gold were, however, obtained from them.

Some fifty or sixty miles up the river quartz veins of an entirely different character occur, the quartz being hard, white, and saccharoidal, and the gold excessively fine; the country rock here is slate, and the veins appear to be much richer.

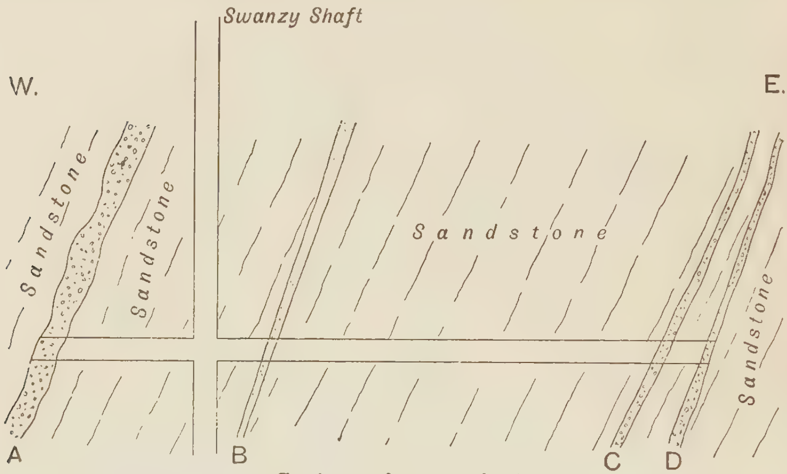
Beds of conglomerate, in every way comparable to those worked in the Transvaal, occur in what may be described as the Wassaw district. There are a number of beds of conglomerate here which have been opened in various places, such as Adjah Bippo, Tacquah, Abosso, Effuenta, Teberibi, Abontyakoon, &c. The formation consists of grits and sandstones, with a general strike between N.E.—S.W. and N.N.E.—S.S.W. and a dip to the S.W., at angles varying from 30° to 70°. The beds of auriferous conglomerate vary in width from two feet to about eight feet. The rock consists of quartz pebbles, cemented together by crystalline quartz, the cementing material containing also a considerable amount of ilmenite and gold in fine bright crystalline particles. As at Witwatersrand, the gold seems to be confined to the cementing material, but, unlike the former locality, no pyrites is met with in depth in the Wassaw deposits; for this reason, these beds show white at their outcrops instead of being stained deep red and brown with oxide of iron, as is the case in the Transvaal. The section, Fig. 114, after a rough sketch kindly furnished by Mr. Sam, the manager of the Wassaw Company's mines, shows the geological relations of the deposit. The Wassaw Company [1] was founded in 1882; operations were commenced on the Crockerville-Adjah-Bippo concessions on two reefs of quartz enclosed in talcose schist, which proved not to be payable, and on the foundation of the Company, the conglomerate and sandstone beds now being worked, were attacked. They are being mined through three shafts, the deepest being now 212 feet; the Swanzy shaft, now (1895) 184 feet deep, is intended to open up the "reefs" at a depth of 330 feet. The Company has also recently acquired the Cinnamon Bippo concession, which is being opened up by adits.

The following results have been obtained at the Wassaw Company's Adjah Bippo mines in recent years:—

Year.	Ore crushed. Tons.	Gold got. Oz.
1893	2,753	4,386
1894	3,384	3,748
1895	3,165	3,872

[1] Communicated by the Secretary of the Wassaw Company.

The total gold produced by the Wassaw Company from the date of its inception to the end of 1895 has been 26,810 oz., worth £104,246. In July, 1896, these mines produced 626 oz.; a rich



Scale 40 feet to 1 inch.

A. Conglomerate "Reef," with pebbles about the size of pigeons' eggs; auriferous.
B. Quartzose sandstone; slightly auriferous.
C. Conglomerate "Reef," 2 ft. thick. } Auriferous, now being worked.
D. Conglomerate "Reef," 2 ft. 3 in. thick. } Auriferous, now being worked.

FIG. 114.—Section across Wassaw Mine at the 150 foot level.

shoot going 4 oz. to the ton had recently been cut, the average richness of the "reef" at the 150 foot level being 1oz. 12 dwts. to the ton.

The following are the returns given officially for the various mines working in the Gold Coast Colony during 1894:—

	Oz.	£	s.	d
Tacquah and Abosso	4,490	16,166	5	0
Gie Apantoo	2,367	8,521	4	0
Adjah Bippo	3,645	13,120	15	1
Cinnamon Bippo	383	1,377	9	9
	10,885	39,185	13	10

The gold dust obtained by the natives (Fantis) of this district is got by sinking narrow shafts, which, though under three feet in diameter, are often as much as ninety feet deep, by means of which they reach the vein or bed as the case may be, and extract as much of it as they can reach from the shaft; they did not seem to be acquainted with the method of driving levels, and only widened their shafts out a little at the bottom. Hence shafts will be found in a rich spot sunk so close together as barely to allow room to walk between them. After the auriferous rock is extracted it is broken into small pieces between two stones, and then rubbed to powder by means of a heavy quern-shaped stone, worked on a larger flat one. The powder so obtained is washed in round wooden dishes, and the gold dust thus collected is an article of commerce. The following table, taken from the official reports, shows the weight and value of gold exported from the Gold Coast between the years 1887 and 1894:—

Exports of Gold Dust from the Gold Coast Colony from the Year 1887 to 1894.

Year.	Weight.	Value.
	Oz.	£
1887	22,546	81,168
1888	24,030	86,510
1889	28,666	103,200
1890	25,460	91,657
1891	24,475	88,112
1892	27,446	98,805
1893	21,972	79,099
1894	21,332	76,796
Totals	195,927	705,347

THE TRANSVAAL.

Gold.—Since the year 1888 the Transvaal has come very prominently to the front as a gold producer, and there are signs that the limits of its importance in this respect are far from having been reached. There are at present some ten recognised gold-fields in the Transvaal, but they are all overshadowed by the extraordinary results obtained in the Witwatersrand district, which alone produces 90 per cent. of the output of the Transvaal, and nearly 20 per cent. of the output of the whole world.

Witwatersrand.—In spite of the enormous amount of gold produced, the area of this field is relatively small; it is, roughly speaking, elliptical in plan, and measures about fifty miles long by ten miles wide, its longer extension being east and west. It is sufficiently remarkable that the gold production of this insignificant area should nearly equal that of vast continents like North America and Australia, whilst the character of the deposits from which the gold is obtained promises an exceptional degree of steadiness and permanence in the maintenance of the output.

As already fully described (see page 58), the gold deposits are beds of conglomerate, impregnated with gold, associated with, and in part contained in, iron pyrites below the permanent water level, above which it has been liberated by the oxidation of the pyrites, whilst near the outcrop an extremely rich zone of concentration had been produced as already mentioned (pages 59 and 98). By means of boreholes the deposits have already been proved to a depth of about 2,500 feet, and deeper bores are in progress. Practically the whole of the gold produced is obtained from the so-called Main Reef series of beds; the Black Reef and others contributing a very insignificant portion to the total. The most successful mine on the Witwatersrand may, perhaps, be said to be the Robinson Mine, the results attained by which may at least be taken as typical of the very best mining practice of the district. In 1895[1] this mine crushed 140,665 tons of ore,[2] distributed as follows :—

Main Reef	36·92 per cent.
Main Reef Leader.	30·86 „
South Reef	32·22 „

From this there was obtained gold as follows :—

By amalgamation . .	120,113	ounces, value	£431,666
From the concentrates .	14,938	„ „	61,723
Total mill yield .	135,051	„ „	493,389
By cyanide (75,825 tons of tailings treated) .	22,157	„ „	72,553
Total gold obtained	157,208	„ „	565,942

The yield is thus 19 dwt. 4 gr. to the ton by direct crushing, and an additional 3 dwt. 3 grains by the cyanide treatment. The value of the gold produced is £4 0*s.* 5*d.* per ton, whilst the

[1] *Directors' Annual Report*, 1895.

[2] In South Africa the ton is taken at 2,000 lbs. avoir. = 0·8929 statute ton.

cost of extracting the above gold, everything included, works out to £210,166, the remainder, or £355,776, being the profit for the year. The cost of mining and milling is given as 19*s.* 2*d.* per ton.

The gold-fields of Heidelberg and of the Nigel district are also working on conglomerate deposits, which appear to form a continuation of some of the deposits of Witwatersrand proper, but their exact correlation has not yet been made out. These fields produced in 1894 about 52,600 oz., and in 1895 about 43,600 oz., this production being included by the Chamber of Mines of Johannesburg in the Witwatersrand output. The following is the total production of gold, according to that Chamber,[1] of the whole Witwatersrand gold-field since the commencement of operations:—

Year.	Ounces.
1887	23,125
1888	208,122
1889	369,557
1890	494,817
1891	729,268
1892	1,210,869
1893	1,478,477
1894	2,024,164
1895	2,277,640
Estimated unrecorded production during the years 1887-89	42,000
Total	8,858,039

Whilst the Heidelberg district appears to form the eastern extremity of the basin-like outcrop of the conglomerate beds, the Klerksdorp and Potchefstroom district seems to be its western termination. The banket here is very similar to that worked on Witwatersrand proper, though it appears near the surface both paler in colour and less consolidated. The most important company in this district is the Buffelsdoorn, which produced in 1894 a total of 49,846 oz. of gold, being close upon two-thirds of the entire production of the district, which amounted in 1894 to 77,714 oz., and in 1895 to 91,206 oz., of which latter figure the Buffelsdoorn Company produced 47,193 oz.

There are other districts in the Transvaal where auriferous conglomerate has been found. It occurs lying almost horizontally

[1] *Seventh Annual Report of the Witwatersrand Chamber of Mines for* 1895, p. 172.

in the face of the steep escarpment of the Duivel's Kantoor, as also in the Lydenburg district, also flat lying; a great deal of work has been done in both these places, but payable conglomerate has not been found hitherto in either locality; the occurrences are nevertheless interesting as showing that similar geological conditions must have prevailed over a very considerable area. A small patch of auriferous conglomerate has been opened up and is being tested at Vryhrid; its yield for 1895 is given as 470 oz. In round numbers, the total amount of conglomerate treated in the Transvaal in 1895 was 3,670,000 (short) tons and the production of gold therefrom 2,369,000 oz., worth about £8,146,000. Auriferous quartz veins also occur in the Witwatersrand district, for example at Kromdrai, but are not of much commercial importance, except from the fact that it was the discovery and working of these that led to the discovery of the immense richness of the banket beds.

The Lydenburg district is the oldest known gold-field in the Transvaal. Alluvial was first worked there, chiefly in Pilgrim's Creek and in the Blyde Valley, where it occurred in the form of shallow placers; it also was found in the smaller creeks of the district, mostly tributaries of the first-named, on the properties Mac-Mac, Lisbon, Berlyn, Spitzkop, Graskop, &c. These deposits seem to have been first worked in 1873 with very varying success; some few of the diggers did well, but many barely made a living, whilst it seems that some were unable even to do that. No statistics are available, but it has been asserted that the value of the gold obtained from these alluvial fields is not equal to that of the money spent there; it has been estimated that these placers yielded altogether gold to the value of about £500,000.

Besides the alluvial deposits, gold occurs in the Lydenburg district in various other forms. Extremely rich but very narrow veinlets of quartz, carrying coarse free gold, often in the form of encrusting pseudomorphs after iron pyrites, were worked near the Waterfall Creek; these veinlets were approximately vertical, ramifying in all directions, and were soon worked out. In the same place a quartz vein in a diorite dyke, giving about 6 dwt. of gold to the ton, was worked for a while by the Lisbon-Berlyn Company. At present mining in this district is almost confined to one or more flat-lying beds of very indeterminate character, the richest being known as the Theta Reef in Ophir Hill close to Pilgrim's Rest, worked by the Transvaal Gold Exploration Company, Limited.

It consists apparently of a decomposed quartzite, interbedded with siliceous dolomite and massive quartzites; its average thickness is about three feet though it increases in places to six feet, and it is mostly overlain by a thin bed of black manganiferous clayey matter, which also carries gold, the average assay value of the bed being about 3 oz. to the ton. It would seem as though this bed had been formed by the silicification of a bed of dolomite, only the lime and magnesia being dissolved out, and the manganese carbonate which it originally contained in small quantity being converted into oxide and forming the above thin layer. Concurrently with the silicification of the bed it was also mineralised by gold-bearing solutions, which are in some way connected genetically with the numerous dioritic dykes that traverse the district. The gold of this district is very generally associated with bismutite[1] in small pockets or nests. The Transvaal Gold Exploration Company, Limited, produced in 1893–94 a total of 24,676 oz. from 10,102 tons of ore treated, and in 1895 crushed 28,321 tons, obtaining 33,180 oz. of gold. The total production of the Lydenburg district was 60,275 oz. in 1894 and 63,046 oz. in 1895.

The De Kaap district was at one time very actively worked, but at present has sunk into insignificance with the exception of the Sheba Company's mine, which alone produces over three-fourths of the entire output of this field, which is nevertheless superficially one of the most extensive of the Transvaal. The district consists of highly metamorphic schists and quartzites, which follow the edge of a huge boss of granite that lies to the north of the stratified rocks, whose general strike is therefore about east and west, with dips to the south varying from 45° to nearly vertical. These rocks, both stratified and granitic, are traversed by dykes of diorite and pegmatite, the latter in places carrying a few garnets. In the neighbourhood of the granite, these rocks occasionally carry small ferruginous intercalated deposits, which are generally auriferous, and sometimes rich at the outcrop, and barren at shallow depths; they are also lenticular in horizontal section and hence do not extend far. In some cases, *e.g.*, in the Bullion Reef, the deposit, though small, was workable, this reef having yielded over five ounces of gold to the ton. The Sheba Reef has been described by Schmeisser as a complex deposit consisting of a number of closely conjoined fissure veins, forming thus a complex contact vein,[2]

[1] H. Louis, "Note on the Occurrence of Bismutite in the Transvaal," *Min. Mag.* 1887, vii. p. 139.

[2] *Op. cit.* p. 30.

with a quartzite hanging wall, and diorite of slaty structure on the footwall side. The vein itself, some 120 feet thick on the average, consists of quartz passing in places into quartzite. The footwall is clearly marked, the hanging wall less so, the vein matter passing gradually into the country rock. Horses of the hanging wall rock are often found enclosed in the vein. The richness of the quartz is very variable; near the surface, where a certain amount of local enrichment had no doubt taken place, it has yielded as much as 10 oz. of gold to the ton, but its average of recent years has been about 1 oz. The gold throughout seems to run in shoots which are exceptionally well marked and which dip with the deposit; some of it is coarse, but some is exceedingly fine. The ore contains a small proportion, about 1½ per cent., of pyrites.

It is very doubtful whether Schmeisser's opinion regarding the character of this deposit is correct. It seems far more probable that it is an altered bed than a contact vein; the bed was probably originally quartzose, and has been altered by mineralising solutions making their way along what is now the footwall of the deposit. The impermeable strata on the footwall side were not attacked, but the solution penetrated and altered the bed for a variable distance from this wall; hard portions of the quartzite were not attacked and therefore appear as horses enclosed in the vein. The solution being highly siliceous would account for the hard, close nature of the dark-blue quartz of the deposit, whilst this same explanation also accounts for the gradual passage of the country rock on the hanging side into this typical quartz. It is, in fact, another instance of a deposit formed metasomatically. Under these conditions, it is quite natural to expect the gold to run in shoots, and it is fairly evident why the neighbours of the Sheba Mine, working upon the same line of deposit, have found the bed continuous, but not its rich contents. Whether the shoot will maintain its richness in depth is an open question.

The Sheba Company [1] crushed in 1894 a total of 45,852 tons [2] of ore, and obtained from the mill and cyanide works 73,414 oz. of gold. In 1895 this company crushed 24,875 tons and got altogether 39,428 oz.; this falling off in production had nothing to do with the mine, but was caused by an accident owing to which the mill did very little work for four months. From the date of the discovery of the mine in 1886 up to the end of September,

[1] *Report of the Directors for* 1895.

[2] These are long or statute tons of 2,240 lbs.

1895, the total production of gold has been 258,205 oz., worth[1] £972,663.

On Moodies' there are at any rate two well marked lines of reef, which are apparently fissure veins, very nearly, if not quite, parallel to the stratification of the enclosing country rocks. The principal line is known as the Pioneer, the other one to the north of the former as the Ivy reef. Each of these reefs have parallel branches; the country rock of the Pioneer reef is mostly bright green chloritic schist, that of the Ivy reef talcose schist, the stratification being traversed by several dioritic dykes. The reefs run about east and west and are nearly vertical, dipping, if at all, to the south. These veins are of very white quartz, in marked contrast to the colour of the quartz from the Sheba Mine. The gold occurs in well-marked shoots which tend to dip to the east, and is generally rather coarse; it is extremely patchy, so that the results obtained in this district have not been equal to the expectations at first formed of it. In 1894 the output of the Pioneer Company was 666 oz., and that of the United Ivy 3,489 oz.; the latter company produced 2,226 oz. in 1895.

Included in the De Kaap gold-field is the curious occurrence of gold on the Duivel's Kantoor. Here considerable amounts of so-called alluvial have been obtained from time to time; it is not, however, true alluvial, but consists of particles and masses of highly crystalline gold, which appear to occur in the soil formed by the weathering of the rocks *in situ*; fragments of quartz, &c., occur in this ground with sharp edges and not as rounded pebbles; cubes sometimes ¾-inch in the edge of limonite, pseudomorphous after pyrites are plentiful; the gold, which sometimes forms encrusting pseudomorphs after pyrites, but is generally in crystalline masses of say 1 dwt. to 50 oz. in weight, is usually coated with a crust of oxide of iron, which is at times manganiferous. The appearance of the deposit suggests that simultaneously with the weathering of these rocks, gold either disseminated through them, or contained in thin quartz reefs which traverse them, entered into solution and was at once re-precipitated, possibly by the sulphate of iron which was also being formed by the slow oxidation of the cubes of pyrites; it may be added that the pyrites, itself oxidised to limonite, gave no gold on assay. These so-called alluvial deposits produced about 600 oz. of gold in 1894 and about the same in 1895. Near the Duivels Kantoor the Barretts Berlyn Company is mining a mass of highly decomposed felspathic

[1] *Report of the Directors for* 1895.

rock traversed by thin auriferous veinlets, which may be described as a kind of stockwork. This company produced in 1894 a total of 4,358 oz. of gold, and thus took the second place as a gold producer on the De Kaap fields, although its output was only one-seventeenth of that of the leading mine, namely the Sheba. In 1895 the output was 6,198 oz. The following table shows the production of the De Kaap fields since the beginning of active operations in 1885 :—

Year.	Production.
1885–86	17,269 ounces.
1887	25,817 ,,
1888	48,891 ,,
1889	35,002 ,,
1890	23,710 ,,
1891	61,385 ,,
1892	63,125 ,,
1893	67,497 ,,
1894	92,577 ,,
1895	63,046 ,,
Total	498,319 ,,

The numerous other less important gold-fields that are recognised all over the Transvaal, as well as in the adjoining districts of Swaziland, present no features of especial interest; the gold mostly occurs in quartz veins, which are generally of the bedded vein type, and it is noticeable that they are for the most part associated more or less directly with the existence of diorite dykes, which seem to exert in some way an influence upon the presence of the gold. The table [1] on following page gives the details of the production of gold in the Transvaal between the years 1890 and 1895.

The value [2] of the output from the different districts for 1895 is given as follows :—

Witwatersrand	£7,840,779
Klerksdrop and Potchefstroom	304,886
De Kaap	219,138
Lydenburg	174,712
Zoutpansberg	32,000
Malmani	3,008
Other districts	3,027
Total	£8,577,550

[1] *Report of the Chamber of Mines*, Johannesburg, 1895. [2] *Ibid.*

Table showing the Output of Gold in the Transvaal from the Year 1890 to 1895 inclusive.

Districts.	1890.	1891.	1892.	1893.	1894.	1895.
Witwatersrand . .	494,817	729,238	1,210,869	1,478,477	2,024,164	2,277,640
Klerksdorp and Potchefstroom.	10,358	10,682	8,968	24,407	77,714	90,841
De Kaap	20,735	61,385	63,125	67,497	92,577	63,046
Lydenburg . . . } Zoutpansberg (Klein Letaba) . . . }	14,315	23,903	24,092	29,329	60,275	63,506
Zoutpansberg (Klein Letaba) . . .		7,926	14,694	6,588	9,174	8,726
Malmani	—	—	2,061	1,719	494	829
Other districts . .	—	—	1,585	2,318	1,455	824
Totals . . .	540,225	833,134	1,325,394	1,610,335	2,265,853	2,505,412

Other Metals.—In addition to gold, the Transvaal is rich in deposits of the ores of other metals, which have, however, been comparatively neglected hitherto. The most important, perhaps, are veins of argentiferous galena, which have been found in the Pretoria district traversing granites and associated with diorite dykes. The gangue consists of quartz and spathic ore, the metallic minerals are argentiferous galena, some copper ores, and zinc blende. But little work has been done on these deposits. Copper ores and lead ores are reported from various districts as also iron ores, but none of these have as yet been worked. Rich magnetic iron ore is said to occur in the Middelburg district, in which a deposit of manganiferous cobalt ores was worked for some years about 1875. Tinstone is said to occur in the Komati district, but has not, so far, been worked to any extent; a few tons seem to have been shipped to England. Cinnabar occurs in the same district, and is also reported near Pretoria. On account of the great difficulty and expense of transport, and the absence hitherto of any local demand, no mines except gold mines have been found worth working.

Gold has also been found in countries bordering on the Transvaal, in Swaziland to the south-east, and Mashonaland and Matabeleland to the north. In Mashonaland gold reefs that have been extensively worked by some ancient race of which we have no other records, have been met with. Some of these are said to be rich, but most of the statements respecting them emanate from interested parties, and must be received with caution. It seems undoubted that auriferous quartz reefs, apparently fissure veins, exist in the Chartered Company's territories, but although they have now been worked energetically for some years, the production of gold has been limited to a few thousand ounces. It cannot be said that anything definite is really known about them up to date.

NORTH AMERICA.

THE UNITED STATES.

Mr. R. W. Raymond,[1] in a paper on the mining districts of the United States, recalls the fact that W. P. Blake, in a note to his *Catalogue of California Minerals*, first pointed out that the mining districts of the Pacific slope are arranged in parallel zones, following the prevailing direction of the mountain ranges. More recently Clarence King has summarised these phenomena nearly as follows: The Pacific coast ranges carry, on the west, quicksilver, tin, and chrome iron ores. The next belt is that of the Sierra Nevada, and of the Cascade Mountains of Oregon, which, upon their western slope, carry two distinct zones, a foot-hill chain of copper mines, and a middle line of gold deposits, which extend into Alaska. Lying to the east of this zone, along the eastern base of the Sierras, and stretching southward into Mexico, is a chain of silver mines which are frequently included in volcanic rocks. Through Central Mexico, Arizona, Central Nevada and Middle Idaho there is another line of silver mines, which more often occur in the older rocks. Through New Mexico, Utah and Western Montana lies another zone of argentiferous galena lodes, and again to the east the New Mexico, Colorado, Wyoming and Montana gold-belt forms a well-defined and continuous chain of deposits. Raymond agrees that this parallelism exists, although in a somewhat irregular way, and that it is chiefly referable, as Blake and King have shown, to the structural features of the country. East of the Rocky Mountains there is but one longitudinal range, namely, that of the Alleghanies, which is accompanied by a gold-bearing zone of irregular extent and value. The immense mining activity of the last twenty years has brought to light a very large number of ore deposits whose distribution does not always fit in with the above scheme. The quantity of mines of all kinds now being worked in the United States is so great that it would be impossible to give anything like a complete account of them within the limits of the present work, hence the more important or the more remarkable deposits can alone be here referred to.

[1] *Trans. Amer. Inst. Min. Eng.*, i. 1873, p. 33.

Gold and Silver.

The gold-fields of the United States of America may be divided into three distinct groups, namely:—the Pacific division, the division of the Rocky Mountains, and the Eastern division. As however the first two of these groups sometimes yield both gold and silver from the same deposits, it will be more convenient to include the two precious metals under one heading than to treat of them separately.

Pacific Division.—The Pacific division comprehends California, Nevada, Utah, Arizona, Idaho, Oregon, Washington and Alaska, and, although by far the most productive of the gold regions of the United States, it is by no means the oldest of them, gold having been first discovered in large quantities in California only in the year 1848. This State still continues to yield the largest amount of gold of any of the States or Territories of the Pacific division, but its production of silver is comparatively small.

The principal gold-bearing belt of California [1] extends along the lower slopes of the Sierra Nevada for a distance of more than 700 miles, and varies in width from twenty to sixty miles. The central mass of the Sierra consists of granite, which is flanked by clay slates, mica schists, chloritic schists, talc schists and hornblendic schists, sometimes associated with quartzites and limestones. The strike of the sedimentary rocks constituting the auriferous belt is nearly north and south, and the enclosed veins of gold-bearing quartz generally course in a direction nearly parallel to its longitudinal axis.

The first statement relative to the age of these rocks was made by J. D. Whitney in 1864, and it now appears to be a well-established fact that a large portion of the auriferous rocks of California consists of metamorphosed Triassic and Jurassic strata, whilst nothing older than Carboniferous has been found in the gold-bearing region. The only fossils older than Triassic which have been discovered to the west of the crest of the Sierra Nevada are those of the limestone belt, of which by far the most fossiliferous locality is at Bass's Ranch, in Shasta County. The

[1] J. D. Whitney, "The Auriferous Gravels of the Sierra Nevada of California," *Memoirs of the Museum of Comparative Zoology at Harvard College*, Cambridge, vi. 1880. *Geological Survey of California*, i. 1865, p. 327. B. Silliman, *Report on the Deep Placers of the South and Middle Yuba*, San Francisco, 1864. Clarence King, "Production of the Precious Metals," *Report of the Secretary of the Interior*, Washington, 1882, iii. p. 335. *The Reports of the California State Mineralogist.*

fossils, which here occur in great abundance, are of undoubted Carboniferous age.

In the southern portion of the State there are several gold-fields of subordinate extent, many of which may be regarded as practically exhausted, and which are now chiefly interesting as having furnished the earliest evidence of the existence of gold in California. Some of these southern placers are said to have been known to the Spanish missionaries long previous to the date generally assigned to the first discovery of gold, but they, for prudential reasons, prevented as far as possible the spread of rumours respecting the existence of gold in the vicinity of their mission lands.

The original source of the gold of California is undoubtedly in the veins of gold-bearing quartz which occur abundantly in the slates and other metamorphic rocks of the western slope of the Sierra. Historically, however, these veins of auriferous quartz are secondary to the shallow and deep placer diggings, in the former of which the first gold found in the State was discovered, and which for some years furnished nearly the whole of the gold produced in the country. There can be but little doubt that the gold in the auriferous gravels was originally derived from the degradation of veins of gold-bearing quartz, and the distribution of the detritus thus produced by the mechanical agency of water. It has also been conclusively proved that the gold-bearing gravels of California belong to two distinct periods, both of which are comparatively modern; those of the later period being distinctly separated in time from those of the earlier, from the breaking-up and re-distribution of the materials of which the later gravels chiefly derive their origin (*see also* page 20).

The sources from which Californian gold has been derived are consequently the following :—

1st. The distribution of placer gold by the present river system, giving rise to shallow diggings.

2nd. The distribution of placer gold by an ancient river system in beds of sand, gravel, and pebbles, known as deep diggings.

3rd. Gold-bearing quartz veins enclosed in metamorphic rocks.

The attention of the first miners was exclusively directed to the shallow placers, in which the gold lay near the surface, and within the reach of those whose whole capital consisted of ordinary mining tools. Here their labour was often abundantly remunerated, whilst the skill necessary was comparatively limited.

In proportion as these surface deposits became impoverished and gradually exhausted, appliances were, by degrees, introduced for sluicing and collecting gold, requiring the employment of an increased amount of skill and a somewhat larger capital. Finally, it was discovered that extensive auriferous deposits were to be found at levels far above the course of the present streams, and an entirely new method of working became necessary. In order to meet these new conditions the system now known as the hydraulic process was invented, and deep diggings were inaugurated.

The gravels and cements of the deep diggings of California so closely resemble the deep leads of Australia, both in composition and in geological age, as scarcely to require a detailed description. As, however, the conditions in the two countries are not absolutely identical, a short abstract of Professor B. Silliman's description of the deep placers on the Yuba River may not be without interest.

In this locality the auriferous gravels have frequently, where they have been exposed to denudation, a thickness of 120 feet, and of more than 250 feet where they have been protected by a volcanic capping. These immense deposits consist of rounded fragments of quartz, diorite, syenite, and of all the metamorphic rocks found above them in the Sierra. They often enclose iron pyrites, and are frequently so cemented together as to form a hard conglomerate. In some instances these auriferous deposits have been found in the immediate vicinity of gold-bearing quartz veins, and have therefore, in such cases, been formed *in situ*. They are often locally stratified, but there is usually no continuity in the bedding. Generally speaking, the lower portions consist of larger boulders than the upper, but this does not exclude the appearance of large rounded masses of rock in the middle and upper members of the series.

When a fresh section of one of these deposits is exposed, such as may be seen in hydraulic claims in active operation, a marked difference will be observed between the colours of the upper and lower portions of the mass. This is chiefly caused by the oxidation of iron pyrites through the action of surface water, thus staining the gravels red or brown in undulating lines contrasting strongly with the blue colour of the unoxidised detritus. The blue coloured portions of these gravels are highly impregnated with iron pyrites, which forms one of the chief cementing materials by which they are held together. Isolated patches of fine sand, frequently exhibiting indications of false bedding, are often observed in the upper portions of the deposit, and in these are found large quantities of silicified fossil wood, which, although retaining its original structure, is frequently flattened by pressure and blackened to the colour of coal. Analyses of two specimens of this wood will be found on page 22. In some instances these auriferous gravels are covered by a volcanic capping in the form of basalt, and in such cases the fossil wood is almost always beautifully silicified. Gold is, to some extent, disseminated throughout the whole mass of these great gravel deposits, but is always in greatest abundance near the bottom, and especially in direct contact with the bed-rock, which is usually grooved and polished by glacial or aqueous agency.

After the removal of the superincumbent gravels by the hydraulic process, the grains and scales of gold remaining upon the

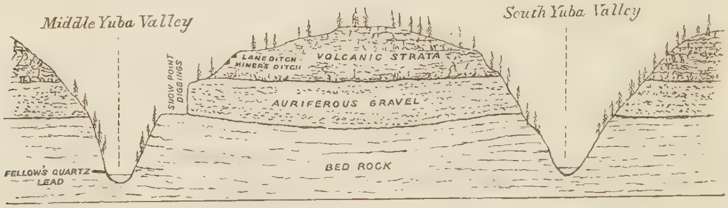


FIG. 115.—Section between the Middle and South Yuba Rivers.

bed-rock are sometimes brilliantly conspicuous. These are, in many cases, inlaid so firmly upon the hard granitic bed of the ancient river course as to resemble a gilt mosiac, and the whole surface of the rock has to be worked over by the pick in order to secure the gold entangled within its substance. In cases where the bed-rock consists of comparatively soft materials such as mica schist or clay slate, it is usually found advantageous to break it up to a depth of from eight to ten inches in order to liberate the enclosed gold.

The ridge of land which is embraced between the Middle and South forks of the Yuba River is from six to eight miles in width, and, to the limits of the auriferous gravel, extends altogether about thirty miles, thus forming an area of approximately two hundred square miles. The more elevated portions of this ground are covered by a heavy bed of volcanic ashes and breccia, as seen in Fig. 115, which represents a section upon a line drawn from the Fellows Quartz Lode, on the Middle Yuba, south-east, through Snow Point and Mount Zion to the South Yuba, having once formed a continuous sheet over a region of considerable extent. This mass of volcanic ashes contains angular fragments of cellular lava, trachyte, basalt, porphyry, and of various other rocks foreign to the general geology of the country.

The extent of the gravels constituting the deep diggings of California is very large, and in some instances their richness has been remarkable. A French engineer who visited California many years ago states that, at Mokelumne Hill, 250 lbs. of gold had been extracted from a few centimetres of material lying immediately above the bed-rock, within an area of fifteen square feet.[1]

A remarkable deposit of auriferous gravel has been extensively worked under Table Mountain in Tuolumne county, the summit of which is occupied by a thick bed of basalt, in some places distinctly columnar. This basaltic capping is, in the neighbourhood of Sonora, 150 feet in thickness, and near the entrance of the celebrated Buckeye Tunnel its width is about 1,700 feet. Beneath this lava is a heavy deposit of sedimentary material, consisting chiefly of a fine-grained sandstone interstratified with seams of clay and argillaceous shale. With these are associated beds of a strongly cohering conglomerate or cement, whilst at the bottom is found the ordinary pay gravel. In California, as in Australia, these lava-capped deposits are mined by means of shafts and levels.

The metamorphic rocks, which form a comparatively narrow zone, running from north to south along the western flank of the Sierra Nevada, contain numerous and important veins of auriferous quartz.[2] These are not by any means equally distributed throughout the whole region of slates, but are chiefly concentrated in a belt having a width, from east to west, of some fifteen or twenty miles, and extending from north to south the whole length of the formation. These veins, for the most part, follow the general strike of the strata in which they are enclosed, although this parallelism is not always absolute. In many cases a vein, besides having a direction somewhat differing from that of the bedding of the enclosing rock, throws off strings and branches traversing the slate at considerable angles.

The gangue of the auriferous veins of California is invariably quartz, which is crystalline and semi-transparent, and contains a little alumina together with traces of potash. In many cases the quartz constituting an auriferous vein is ribboned in such

[1] P. Laur, "Du Gisement et de l'Exploitation de l'Or en Californie," *Ann. des Mines*, iii. 1863, p. 412.

[2] J. A. Phillips, "Notes on the Chemical Geology of the Gold-fields of California," *Phil. Mag.*, xxxvi. 1868, p. 231.

a way as to present the appearance of a succession of layers parallel to its walls, one or more of these laminæ being often more productive than all the others. In some instances these parallel bands are separated from one another by thin layers of quartz differing either in colour or structure from that forming the seams themselves. In some cases, however, laminæ of the enclosing slates divide the vein into distinct bands, and in such instances the thickness of the interposed film of slate is sometimes not greater than that of the thinnest paper. Cavities or druses lined with crystals of quartz are occasionally, although rarely, found in the auriferous veins of California, but, generally speaking, quartz crystals seldom occur in notable quantities in the more productive veins. When the structure of a vein is highly crystalline, and the quartz more than ordinarily transparent, it is considered an unfavourable indication with regard to its auriferous character. The quartz of the gold-bearing veins of the Pacific slope of the Sierra Nevada is, as a rule, comparatively free from the fluid cavities which are of such frequent occurrence in that of ordinary lodes.

The minerals usually associated with gold in the auriferous veins of California are iron pyrites, blende and galena, with, less frequently, mispickel, magnetic pyrites, copper pyrites and cinnabar. These sulphides invariably enclose gold, and veins in which some one or more of them does not occur in notable quantity, are not often lastingly productive. In many cases tellurides also occur in small quantities, and then the vein is generally rich; the tellurides themselves also carry a great deal of gold, and compounds of gold with tellurium, such as sylvaite and petzite, also occur, especially in Calaveras County. Near the outcrops the iron pyrites and other sulphides become decomposed by the action of air and the percolation of surface waters, staining the quartz of a red or brown colour, and leaving the gold in a form favourable for amalgamation. In such cases moulds after cubical iron-pyrites are at times found in the decomposed veinstone, and, although that mineral has been entirely removed, the cavities left by it contain finely divided gold, obviously liberated by the oxidation of the mineral. Beneath the line of the natural drainage of the country the sulphides remain undecomposed, and the extraction of gold has then to be conducted by methods more complex than those of simple amalgamation.

In addition to the gold thus enclosed in the various metallic sulphides, grains and small flakes of that metal are disseminated through the veinstone, and this is especially the case in the vicinity of certain dark-coloured streaks generally almost parallel to the lines of apparent deposition of the quartz. This dark substance is, in some cases, roscoelite, a micaceous mineral containing above 28 per cent. of vanadic oxide. When gold is found lining a drusy cavity or is enclosed in the plastic selvage of a vein, it often occurs in well-formed crystals; but, when crystallisation has taken place in a narrow fissure, the crystals are much flattened and often become plate-like in form.

The veinstone regarded by quartz miners as most "favourable for gold" is seamy, stained by oxide of iron resulting from the decomposition of iron pyrites, mottled, and somewhat resembling marble. In addition to quartz, hydrated silica or semi-opal, and chalcedony have occasionally been observed in auriferous quartz veins, and in some instances the opaline silica is interfoliated between layers of normal quartz, and is conveyed with it to the stamp-mill for treatment. A well-defined band of semi-opal of this kind was visible in the North Star Vein, at Grass Valley, when I (J. A. P.) visited that mine in 1865.

The walls of the auriferous quartz veins are not infrequently smooth and well-defined, and often afford evidence of a considerable amount of faulting. In case of a lead[1] being divided into bands by interfoliations of slate or otherwise, the planes of junction are sometimes marked by deep groovings, indicating that a grinding action has taken place between the adjoining surfaces.

One of the most remarkable gold veins in California is the Great Mother Lode, extending from Mount Ophir in Mariposa County to Mokelumne Hill in Calaveras County, a distance of over seventy miles. This immense lode would be more correctly described in many parts of its course as a mineralised belt, rather than as a simple vein. In some places it only exists as a single lode, the width of which may vary from a thin seam to several hundred feet; often it is split into two or more branches, as, for instance, at Angels Camp and at Carson Hill, where there are two well-marked main branches; in other places, as in Amador County, it is split into a very large number of smaller veins, which form a mineral belt over a mile in width. In some places its outcrop stands out prominently as a high white wall fifteen feet above the level of the surrounding country, and can be followed almost

[1] In California a quartz vein is called a "lead," and in Australia a "reef." In the gold regions of the latter country the term *lead* is applied to the deposits of the deep placers.

continuously on the surface for miles. The greatest depth to which the vein has been opened (twenty-two hundred feet) has shown no weakening of the vein, nor deterioration of the ore.[1] The vein or veins generally occur in a belt of black slate, with either slate, diorite, diabase, serpentine, or, rarely, granite, forming one of the walls. It is undoutedly a fissure vein, parallel to the stratification of the country (about north-west—south-east), and dipping in the same direction, at times quite parallel with it, but at times a few degrees flatter than the dip of the enclosing rocks. The filling material is quartz with a green mineral known as mariposite often disseminated through it, and carrying ankerite in places. The accompanying section, Fig. 116, taken from the

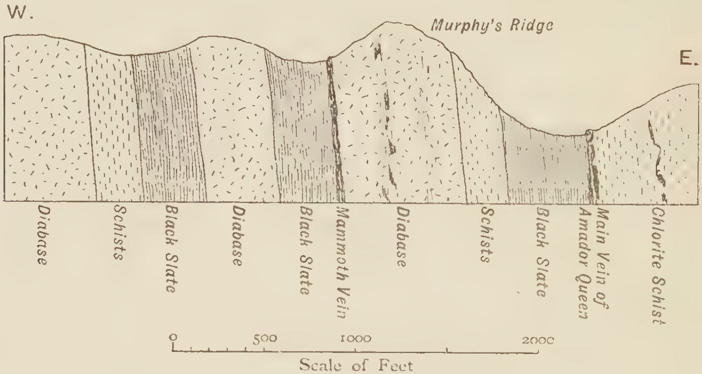


FIG. 116.—Section of the Great Mother Lode at Murphy's Ridge, Amador County.

already quoted paper, gives a good idea of the general geology of the district. The nature of the country rock does not seem to affect the richness or poverty of the vein, and no reason has yet been traced for the richness or poverty of different sections, in which the character of the vein may be exactly similar. Two branches may be found side by side in the same country rock, one of which may be rich in gold and the other practically barren. A most interesting occurrence is that at Kennedy Mine, Amador County, the section of which, Fig. 117, taken from the Twelfth Report of the State Mineralogist, 1894, p. 75, is here given. The vein was first met with at this locality as a contact vein between the west diabase and a belt of slate about eighty feet thick. At a depth of about 370 feet the vein commenced to angle across the slate, and continued through it as a barren fissure containing only crushed

[1] H. W. Fairbanks, "Geology of the Mother Lode Region," *Tenth Annual Report of the State Mineralogist*, 1890, p. 23.

and broken fragments of slate and quartz, and small broken quartz seams, until the fissure had crossed the slate belt at a depth of about 950 feet, where it continued as a contact vein between the slate and the east diorite; the quartz came in again here, and has continued to the lowest depth yet reached, namely, 1,750 feet. There seems to be some evidence that fresh fissuring had taken place after the formation of the mineral vein; in any case, the

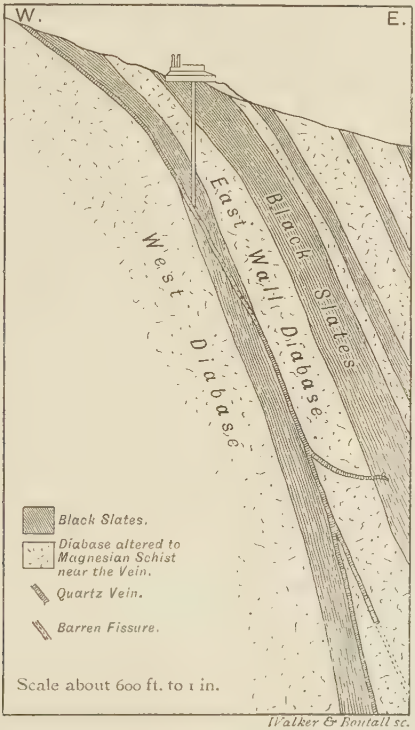


FIG. 117.—Section across the Mother Lode in the Kennedy Mine, Amador County.

fact of a rich and well-defined pay shoot continuing down in depth after having pinched near the surface, and left only a barren crevice in one place for more than 1,100 feet, deserves to be put on record. It is highly probable that numerous such occurrences have been abandoned at various times as having been worked out, when deeper sinking might have disclosed the existence of good veins.

The walls of the Mother Lode are not always well defined, the lode passing in places gradually into the country rock; and there seems evidence to prove that a comparatively narrow fissure or fissures have been mineralised by solutions which have in places penetrated into the wall rock, and mineralised it by metasomatic action. One of the most important mines on the Mother Lode is the Utica-Stickles, near Angels Camp, where diabase has by pressure and chemical action been metamorphosed into talcose and chloritic schists, with threads, bunches and veinlets of auriferous quartz, the whole mass of rock being sometimes worth taking out and milling for a width of 100 feet. One of the most famous mines was the Plymouth Company's mine which was worked on a large body of low grade ore to a depth of 1,600 feet. A fire in the mine in 1888 did a great deal of mischief, and though the mine was re-started in 1890 it soon closed down again. This mine was at its best about the year 1887 ; in that year there were crushed about 120,000 tons[1] of quartz, and gold to the value of $736,000 was produced. From the formation of the company in 1883 to the end of 1887, close on four million dollars' worth of gold was obtained ; the mines which were consolidated to form the Plymouth Company's property produced, before their amalgamation, about two and a half million dollars' worth of gold.

The Mother Lode extends through the five counties, Mariposa, Tuolumne, Calaveras, Amador and El Dorado ; these five counties produced gold to the value of $4,519,147, say about 218,670 oz. of fine gold in 1894. In 1895 their production was $4,693,323, equal to about 227,096 oz.

Nevada used to produce more gold than any other county in California, and is now occasionally equalled or surpassed only by Calaveras and Placer counties ; its yield during the year 1881 was estimated at $3,700,000.[2] In this county there are some important quartz mines, nearly all of which are situated in the immediate neighbourhood of the town of Grass Valley. Of these mines the Idaho is the principal, and during the year 1881, crushed 27,945 tons[3] of quartz, which yielded 30,965 oz. of gold.

About the year 1881, among the richest quartz mines of California were those of the Bodie district, situated in Mono County.

The following description of this region is from a report by

[1] *Fifth Annual Report of the Plymouth Consolidated Gold Mining Company.*

[2] In American statistics of production, the assay value of bullion is given in dollars ; the value of an ounce troy of fine gold is $20·6718, whilst the commercial value of an ounce troy of silver was $1·2929 up to about 1874, about $0·935 in 1889, and about $0·65 in 1894, though the coining value of $1·2929 per ounce is still often given in official statistics.

[3] The American ton weighs 2,000 lbs. avoir. = 0·8929 statute ton.

B. Silliman made in the year 1864.[1] Bodie Mountain, the point of chief interest in the mining district of the same name, is one of the highest inhabited points within the limits of the United States, its summit being 9,500 feet above the level of the sea. The general aspect of the country is desolate, the mountains are bleak and precipitous, and the cliffs broken into rugged steeps strewn with fragments of decomposing rock. Bodie Mountain is an isolated mass of trachytic porphyry, consisting of a lavender-coloured ground-mass enclosing crystals of a white felspar, and facts appear to point to the conclusion that the whole region, at a not very remote geological epoch, was the centre of great eruptive energy. In Mono Lake, twelve miles distant from Bodie, traces of these ancient fires still exist, as is evidenced by the escaping jets of hot vapour, and the numerous boiling fountains which occupy the islands in the centre of the lake. A close examination of the district leads to the conclusion that Bodie Mountain is an island of eruptive rock, having a length somewhat exceeding two miles with a width of about one mile, its crest being subdivided into three prominent points known repectively as Bodie Bluff, High Peak, and Silver Hill.

The whole surface, to the summit, is covered with *débris*, the porphyry in its decomposition having furnished an ochreous earth, in which are seen abundant fragments of quartz, jasper, chalcedony, and other veinstones derived from the breaking up of the crests of the various lodes which intersect the mountain in a general course of N. 25° E. An exploration of the surface of the mountain resulted in the discovery of sixteen nearly parallel quartz veins, which are described with considerable detail, and the author proceeds to remark :—

"They are all, at surface, hard, compact, uncrystalline chalcedonic quartz, sterile of metal, and unpromising for mining explorations; at a pretty uniform depth of forty or fifty feet from the surface they gradually lose these characteristics, becoming softer as we descend, the quartz assuming more and more a fissile and friable character; the compact or chalcedonic portion, greatly diminished in bulk, forms now a lining upon one or again upon both sides of the vein, or, more rarely, a seam of varying width in the centre of the vein, patches or "horses" of the adjacent porphyry occasionally diminishing the vein, which immediately beyond assumes again the largest proportions.

[1] B. Silliman, *Report to the Empire Gold and Silver Mining Company*, April, 1864.

"The metallic contents are found distributed, usually invisible to the eye, but indicated by dark coloured stains parallel to the surfaces of the quartz, and, when visible, rarely seen in particles larger than grains of mustard seed, and of a spherical or rounded form rather than in plates or scales.

"The observer accustomed to the character of auriferous quartz in other portions of the United States, or elsewhere, is struck also with the remarkable absence of the metallic sulphurets. Mispickel, so commonly the associate of gold elsewhere, seems here to be completely absent; even yellow iron-pyrites and magnetic pyrites are rarely seen. Magnetic iron ore is pretty uniformly found, however, in minute particles, when samples of these ores are washed in the ordinary manner."

Professor Silliman observes that it is obvious from the foregoing statements that the Bodie district is one of the most valuable localities for the precious metals hitherto discovered in the United States. W. P. Blake, about the same period, remarks with regard to the Bodie veinstone that, instead of being a solid homogeneous mass, it is formed in layers or coats one over another like sheets of paper or paste-board, with irregular thin seams or openings between. "This structure, with other peculiarities, indicates that the veins were deposited gradually in the fissures by thermal springs, similar, perhaps to those now existing at various points along the eastern base of the Sierra Nevada, as for example at Steamboat Springs, Washoe." The most recent investigations[1] have shown that the country rock is really a hornblendic andesite, of which there have been a succession of outflows. The quartz lodes occurring in this rock are fissure veins, and are referable to two series, the younger of which, or the Standard group, faults the older, or Fortuna group of lodes. The Standard lodes have produced nearly 60 per cent. of the bullion produced in the district since 1877, but appears to be unproductive below the 500 feet level, where the vein is represented merely by a barren fissure in the andesite. These ores seem to average about 1 oz. 13 dwt. of gold, and 3 oz. 3 dwt. of silver to the ton, the silver being present in various argentiferous minerals, whilst the gold itself is a bullion containing about 675 parts of gold and 305 parts of silver per thousand. The gold of the older or Fortuna series is a good deal richer in silver than even that of the newer lodes. The latter strike between N. and N. 20° E., dipping westwards, 35° to 85°, whilst the former strike a little west of north, and dip eastward 30° to 50°.

[1] *Eighth Annual Report of the State Mineralogist*, 1888, p. 382.

The most productive mine of the Bodie district has been the Standard Consolidated, which employed about 150 miners. Its depth in 1881 was about 175 fathoms, and its production of gold and silver slightly exceeded $2,000,000; during the year 1882 the total yield of bullion was $2,084,550. The Bodie Consolidated was then taking from sixty-five to eighty tons of ore per week from the Fortuna Vein, and shipping above $7,000 in bullion weekly. The production of the Bodie Consolidated Mine during the year ending June 1st, 1882, was 132,040 oz. of bullion, value of gold $262,421·17; of silver $143,737·08; total $406,158.25.

The bullion shipments from Bodie district in 1881 amounted to $3,173,000, an increase of more than a million of dollars over those of 1878, the year of greatest excitement in the Bodie mines. In 1888[1] there was only one large mine at work, the Standard Consolidated, which produced gold to the value of $118,371, the total output of the district for the year being returned at $126,295. Up to the end of that year Bodie district had produced gold to the value of over eighteen million dollars. The whole of Mono County produced gold valued at $552,690 in 1895.

According to an official return the production of gold in California for the year ending May 31st, 1880, amounted to $17,150,941, or 829,676 oz. troy, of which $8,580,982, or 415,105 oz., were the production of hydraulic, placer, drift, and river mines, and the remainder obtained from the treatment of gold quartz. The Director of the United States Mint estimates the production of gold in California in 1881 at $18,200,000, and in 1882 it was probably something over $15,000,000.

Previous to the discovery of the Bodie district, the placer mines yielded about two-thirds of the gold production of the State, but the large output of the mines in that region, which amounted at one time to above two and three-quarter millions of dollars annually, independent of a considerable production of silver, placed the deep mines almost on a par with the placers as regards the total value of returns. Since that time the output from the quartz veins has been continuously gaining on that from the clastic deposits, and, since legal restrictions (*see* page 23) have been put upon alluvial mining, quartz mining has progressed with rapid strides, and though the total output of gold in California has necessarily fallen off, it is still the foremost gold-producing State in the Union. Now that hydraulic mining is to be resumed, albeit under certain re-

[1] *Eighth Annual Report of the State Mineralogist*, 1888, p. 396.

strictions, an increase in the output, which was already making itself felt to a small degree in 1895, may be anticipated. In 1894 this State produced one-third of the total gold output of the United States, namely 673,700 oz., worth $13,923,282.[1] To this total no less than thirty-one counties contributed, of which the five following produced over $1,000,000 each:—

Calaveras	$2,119,365
Placer	1,851,214
Nevada	1,830,154
Amador	1,331,916
Trinity	1,012,665

In 1895[2] the production was $15,334,318, produced by thirty-three counties, of which the following produced over $1,000,000 each:—

Nevada	$1,789,816
Calaveras	1,717,916
Placer	1,599,635
Amador	1,391,929
Trinity	1,116,745

The above figures are taken from the excellent annual statistical sheets issued by the Californian State Mining Bureau, an example that might be followed with very great advantage by the other States of the Union.

The amount of silver contributed by California is comparatively small, and though chiefly obtained in the adjoining counties of Mono and Inyo in 1880, is now produced principally in San Bernardino and Inyo counties. The former produced $148,243 in 1894, and $219,410 in 1895, the latter $83,640 in 1894, and $188,329 in 1895. The total production of California in these years was respectively $297,332[3] and $599,790.[4]

The production of the precious metals in the State of Nevada showed in the tenth census year, ending 31st May, 1880, a considerable decline as compared with that of the preceding years, which has continued to the present time. This is, however, to be entirely accounted for by the falling off in the yield of the Comstock Lode, and is not due to any decline in the general mining

[1] *California State Mining Bureau, Bulletin*, No. 7, 1895.
[2] *Ibid*, No. 8, 1896.
[3] *California State Mining Bureau Bulletin*, No. 7.
[4] *Ibid*, No. 8.

prosperity of the State. The most remarkable metalliferous deposit in the State of Nevada is unquestionably the Comstock Lode, situated on the eastern side of Mount Davidson and partly underlying the towns of Virginia and Gold Hill. In addition to numerous papers scattered through the pages of various scientific publications, some very important memoirs of a more special character have been written upon the Comstock Lode. In 1865 Baron v. Richthofen made an examination of this district, the results of which were printed by the Sutro Tunnel Company, and in 1867 the same able geologist published a second paper, entitled "A Natural System of Volcanic Rocks," as a memoir of the Californian Academy, the classification proposed being avowedly, to a great extent, based on the geology of the Comstock region.

At the date of the publication of these papers microscopical petrography was still in embryo, and it is consequently not to be wondered at that subsequent investigations, aided by the use of the microscope, have led to somewhat modified petrological results; but so far as the structure and formation of the vein itself are concerned the views of v. Richthofen have been confirmed in a remarkable manner by the results of subsequent investigation.

In 1867 Mr. Clarence King, at that time in charge of the exploration of the 40th Parallel, made an examination of the lode down to the 800-foot level, and, although accepting v. Richthofen's propylite, he at the same time expresses a doubt whether eventually it might not be found identical with andesite. The quartzose rock which v. Richthofen had determined as a Pre-Tertiary quartz-porphyry, King regarded as quartz-propylite. In 1875 the rocks of this district were microscopically examined by Professor F. Zirkel, who confirmed the independence of propylite and quartz-propylite as lithological species, and regarded the quartzose rock as dacite; he also corrected the determination of the granular diorite, which had been called syenite, and added augite-andesite, rhyolite, and a variety of basalt to the list of rocks previously recognised. In 1877 Mr. J. A. Church examined the workings down to the 2,000 foot level. The memoir of this gentleman contains various original hypotheses, amongst which the two following are conspicuously prominent, namely: that the ores were deposited by substitution for propylite, and that the heat of the Comstock Lode is due to the kaolinising action of surface waters on the felspars of the country rock. Finally, Mr. G. F. Becker, under the direction of the Hon. J. W. Powell, has prepared a monograph on the geology of the Comstock Lode. Of this report on the Comstock and Washoe districts a summary had already appeared in 1882.[1]

According to the United States Geological Survey[2] the Virginia Range has resulted from a Post-Jurassic disturbance, attended by the phenomena of folding and compression acting horizontally. It has also passed through an era of disturbances in Tertiary and Post-Tertiary times, during which the vertical component of the dislocating force was greatly in excess of the horizontal. This disturbance consequently resulted in a great amount of faulting throughout the whole region, but was not attended by extensive lateral compression or by folding. The era of Post-Jurassic disturbances was marked by the emergence of three massive rocks, namely, granite, diorite, and diabase. During the Tertiary and Post-Tertiary periods no less than eight different volcanic rocks were ejected ; these have been described by American geologists as propylite, quartz-propylite, hornblende-andesite, dacite, augite-andesite, trachyte, rhyolite and basalt. All of these rocks occur within a mile and a half of the Comstock Lode, and there is a point at the southern end from which a circle can be drawn with a radius of one and a-quarter miles, enclosing occurrences of the whole of them. Mr. Becker, after a careful study of a large number of thin sections under the microscope, has, however, arrived at the conclusion that the rocks which have been classed as propylite in the Comstock district are merely decomposed forms of species previously known.[3] He enumerates the rocks occurring in this region as granite, metamorphic schists, slates and limestones, eruptive diorite of three varieties, metamorphic diorite, quartz-porphyry, an older and a younger diabase, an older and a younger hornblende-andesite, augite-andesite, and basalt.

The Comstock Lode, during the middle portion of its course, occupies the line of contact between masses of diorite and diabase, as seen in the accompanying section, Fig. 118, reduced from Mr. Becker's coloured drawing, in which the dotted portions represent solfataric decomposition. North of the Ophir Ravine it is walled on both sides by diabase ; south of the Gold Hill Divide it leaves the diorite, and is carried southward, principally in diabase, but touches indistinctly the older metamorphic rocks upon its western side. This lode has been traced for a distance of 22,546 feet in a nearly due north and south direction, dips

[1] *Report of the U.S. Secretary of the Interior*, iii. 1882, pp. 293–330.
[2] *U.S. Geological Survey, First Annual Report*, p. 39, 1880.
[3] *Report of the Secretary of the Interior*, iii. 1882, p. xxiv.

towards the east, and has a thickness usually varying from twenty to sixty feet. The vein fissure, which is also a line of fault, was probably formed in Post-Jurassic times shortly after the final extrusion of diorite. The vein matter of the Comstock Lode consists of crushed and decomposed country rock, clay, and quartz. The country rock in and near the vein contains considerable quantities of pyrites and calcite, while gypsum is not of uncommon occurrence. The quartz is, for the most part, crushed into a finely granular mass closely resembling ordinary commercial salt. This quartz was once crystallised, and has evidently been crushed by the movement of the hanging wall upon the foot wall.

The Sutro Tunnel, starting from the Carson Valley, penetrates the eastern country rock for a distance of 20,000 feet, and strikes the lode near the middle of its productive portion 1,900 feet below its highest outcrop. The rocks passed through by the tunnel were hornblende-andesites alternating with augite-andesites,

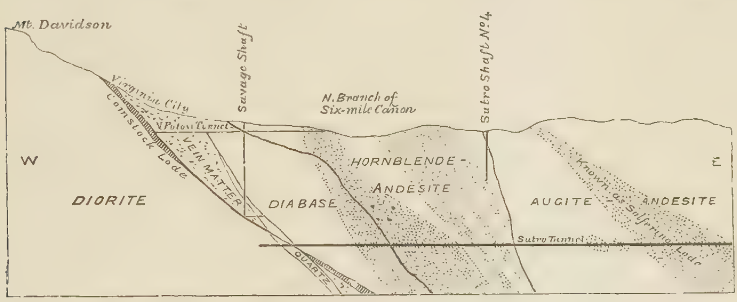


FIG. 118.—Section of the Comstock Lode.

but for the last 1,000 feet before the lode is reached the rock is diabase, whilst beyond it the diorite of Mount Davidson is encountered. The mines upon the Comstock Lode were first opened in 1859, and on June 1st, 1880, the total length of the shafts and galleries in the different mines had already exceeded 150 miles. The number of men employed at that date was 2,770, whilst the aggregate horse-power of the machinery was 24,130, and the greatest depth reached exceeded 3,000 feet, or 500 fathoms.

The most remarkable phenomena in connection with the Comstock Lode is the intense heat which prevails in the lower levels. In the Yellow Jacket Shaft a large body of water was struck at a depth of 3,065 feet, of which the temperature was 170° Fahr., and which was impregnated with sulphuretted hydrogen. In the Forman Shaft there was a gradual increase of temperature amounting on an average to 1° for every 34·2 feet. The heat of the Comstock Lode has been generally ascribed to expiring volcanic agencies, but a few years since it was suggested by Mr. Church that it might probably arise from the kaolinisation of felspars. To the latter theory objections have on more than one occasion been raised,[1] and the recent observations and experiments of Mr. Becker have yielded results by no means in favour of the kaolinisation hypothesis.[2] Some particulars relative to the amount of heat carried off by the waters of the Comstock mines will be found at page 118. With a view of testing the probabilities of Sandberger's theory of lateral secretion, the rocks of the Comstock district have been assayed with all possible precaution by Mr. J. S. Curtis. The constituents of the rocks found to contain the precious metals were separated by Thoulet's method, and the metals thus traced to their mineralogical sources. The results of this investigation furnished many interesting facts, amongst which may be mentioned the following, namely, that the diabase contains a notable amount of the precious metals, of which the larger proportion is contained in the augite; that the decomposed diabase contains about one-half as much of these metals as the comparatively fresh rock; that the relative quantities of gold and silver, both in the fresh and decomposed diabase, correspond fairly well with the known composition of the Comstock bullion; and that the total exposure of diabase is sufficient to account for far larger quantities of bullion than have been extracted from the mines.

In 1876 the yield of the Comstock, according to Mr. Del Mar's estimate, was:—gold $18,002,906, silver $20,570,078; total $38,572,984. During the tenth census year the whole Comstock district, including the Virginia, Gold Hill, and Devil's Gate sub-districts; the outlying veins, such as the Occidental, &c., and the yield of tailings worked at various points throughout the entire tract known as the Washoe Country, was:—gold $3,109,156, silver $3,813,174; total $6,922,330; showing a decline of $31,650,654 or 82·06 per cent. since 1876. During the eleventh census year (1889) the output was: gold, $10,896, and silver $150. Owing to the heavy fall in the price of this latter metal, it is no longer prospected or mined for as vigorously as used to be the case. From

[1] J. A. Phillips, *Quart Jour. Geol. Soc.*, xxxv. 1879, p. 390; *Nature*, xxii. 1880, p. 337.

[2] G. F. Becker, *A Summary of the Geology of the Comstock Lode*, Washington, 1882.

the time the first mines were opened in 1859 to June 1st, 1880, the Comstock Lode had produced about $315,000,000 worth of bullion, of which $175,000,000 was silver and the remainder gold. Out of the above total yield about $115,871,000 had been paid in dividends. In the thirty years up to 1889 the total production had been about: gold $125,000,000, silver $195,000,000.[1]

Some of the most productive silver mines in the State of Nevada are situated in the Eureka and Ely districts. The White Pine region, which, after the discovery of the mines in 1868, was the scene of great excitement, now yields comparatively small returns. The Eureka district consists mainly of metamorphic limestones exhibiting traces of stratification, lying on quartzite and overlain by shale. In these limestones, which are partly of Cambrian and partly of Silurian age, are distributed irregular chimneys and pockets of ore consisting of galena with sulphate and carbonate of lead. This ore usually contains about 25 per cent. of lead, and 50 oz. of silver per ton. The Richmond and Eureka Consolidated, both situated in the southern portion of the district, are the most productive mines.

Throughout this district a great ore-channel extends along the eastern base of Prospect Mountain for a distance of twelve miles. This appears to be a contact deposit in a formation of limestone, quartzite, shale, &c., and from the various mines scattered along the main deposit and its various branches above fifty millions of dollars have been extracted. The Richmond, which is the property of a London company, was in its time reputed to be one of the best paying mines in America, and had reached in 1881 a depth of 1,230 feet below the surface. The Richmond furnaces had at one time the reputation of being the largest producers in the world, and the accumulation of lead in that company's premises in July, 1881, was about 50,000 tons of market metal, there being an acre of ground outside the refinery piled solidly five feet high with pigs of lead. This mine during the first nine years of its existence produced $61,000,000 of bullion. Of the total yield of the ore 33 per cent. is gold and 66 per cent. silver, with a production of one ton of lead to five tons of ore smelted; 500 men were employed at the mine and furnaces, 500 more furnishing fuel, &c.

The Eureka Consolidated has had from the time it was first opened, about 1868, a prosperous existence. The output for the quarter ending September 30th, 1881, was $305,074, and, according to published statements, bullion to the value of $1,396,618 was

[1] *Eleventh U.S. Census,* "*Mineral Industries,*" p. 118.

shipped during the year.[1] In 1889 Eureka County produced 16,360 tons of ore, which yielded: gold $178,940, silver $1,060,297.

The yield of the placer mines of Nevada is comparatively insignificant, as no important gravel deposits provided with a suitable water-supply are known. The total production of bullion in this State during the tenth census year was: gold $4,888,247, silver $12,430,666. During the eleventh census year it was: gold $3,506,295 (= 169,617 oz. fine gold), and silver $6,072,241 (= 4,696,600 oz. fine silver). In 1894[2] the output of the State was:

Gold (fine) 55,042 oz., worth $1,137,819.
Silver (fine) 1,305,151 oz.

Utah has been a regular bullion producer for many years. Gold and silver ores were discovered in 1863, and active mining commenced in 1870. From the beginning of 1871 to the end of 1886, Utah produced 135,135 oz. of gold, and 59,065,016 oz. of fine silver.[3] The proportion of gold annually obtained is small as compared with that of silver, and the only placer gold produced, amounting in the tenth census year to about $20,000, was from West Mountain district in Salt Lake County. About one-fifth of the total production of bullion in this Territory appears during that year to have been supplied by the mines of the Ontario Silver Mining Co., which are situated near Park City, Utah, thirty-two miles east of Salt Lake, and at an elevation of about 8,000 feet above the sea. The principal mining claims belonging to this company are the Last Chance, Ontario and Switzerland, extending on a line on the direction of the lode, and each 1,500 feet in length by 200 feet in width. The vein fills a strong, well-defined fissure having a course nearly east and west, with a northerly dip varying from vertical to 70°. The vein fissure traverses a belt of quartzite, cutting through the layers of the formation unconformably both on the dip and the strike. On the north, or hanging wall of the vein, is a dyke of gray porphyry 100 feet in width, intersecting the bedding of the quartzite with a general course nearly parallel to the lode. On the east this porphyry approaches closely to the vein and in some places even

[1] *Report of the Director of the Mint upon the Production of Precious Metals in the U.S.*, Washington, 1882, p. 129.

[2] *The Mineral Industry for* 1894, p. 278.

[3] O. J. Hollister, "Gold and Silver Mining in Utah," *Trans. Amer. Inst. Min. Eng.* xvi. 1887, p. 3

forms its wall. Towards the west it diverges and is separated from the vein by a variable thickness of quartzite.

The lode has been explored on its course by underground workings for a distance of nearly 6,000 feet, the deepest point at which it has been cut being at the tenth level or over 1,000 feet below the outcrop. The fissure varies in width from two to twenty feet, the usual width being from four to five feet, and throughout this large extent no faults or dislocations occur, the continuity being unbroken. The filling mainly consists of material derived from the walls, being a mixture of finely ground quartzite and clay, resulting from the decomposition of the encasing porphyry. The ore has been deposited in the fissure in a continuous sheet, extending from the surface as far downwards as the explorations have penetrated, and forming a well-defined shoot of ore. At the surface this shoot had a length of only about 500 feet, the fissure, although continuing beyond the ore body to the east and west, being filled with material derived from the walls and containing but small quantities of mineral. As this shoot was followed in depth it increased in length, until at the sixth level it attained a length of 1,500 feet. Not only has this increased in length as it has been explored in depth, but there has also been a gradual increase in the width of the ore, which in the upper levels averaged only from one foot to one and a half feet, whilst in the fifth and sixth levels it is at least two and a half feet wide, and for considerable distances occupies the whole breadth of the fissure. With this increase in the dimensions of the shoot, the ore has become richer as greater depth has been attained. The first ore worked yielded an average of from $70 to $80 per ton, whilst that extracted from below the fifth level mills from $125 to $145 per ton, and the vein, where cut at the depth of 700 feet, samples still higher.

Below a depth of 400 feet the ore is undecomposed, consisting essentially of argentiferous blende, associated with small quantities of gray copper ore rich in silver, a little galena, and iron pyrites. Nearer the surface the ore has been much changed by oxidation, zinc having been removed, and the silver occurring mostly as chloride with some native silver and oxidised copper and lead minerals. The gangue forms about 35 per cent. of the ore as it goes to the mills, and is composed of clay and disintegrated quartzite. The ore is sometimes massive, although the vein frequently exhibits a banded structure with seams parallel to the walls, yet showing no evidences that the process of formation was interrupted. The ore is soft, friable, easily mined, readily detached from the walls, and is separated from the gangue without difficulty. The mine is very wet, especially in the western ground, necessitating the use of powerful pumping machinery.

The Ontario Mine was discovered June 19th, 1872, and the amount of ore extracted from that date to January 1st, 1877, was 13,604 tons, yielding $1,056,713 gross bullion. From January 1st, 1877, to April 1st, 1881, the quantity of ore mined and milled was 62,601 tons, yielding $6,950,788, a total production of 76,205 tons and a gross bullion value of $8,007,501, being at the rate of $105·08 per ton.[1] Up to 1887 over $20,000,000 of bullion had been taken from it.[2] The Emma and Flagstaff mines, on the famous Emma lode, a vein that lies at an angle of about 45° in a country of dolomitic limestone, was at one time—about 1875—a great silver producer, although its output has now sunk to very small dimensions. The silver sandstone region of Washington County, Southern Utah, has already been described (*see* page 55). The most important of these "silver reef" mines are worked by the Christy and Stormont companies; their ores average $120 to the ton, and their annual production was about 250,000 oz. in 1887. Between 1877 and 1887 the total output was about 3,000,000 oz. The total production of the precious metals in Utah during the census year ending May 31st, 1880, was $5,034,645. During that period the production amounted to: gold $291,555, silver $4,743,090. In 1894[3] it was: gold (fine) 41,991 oz., worth $868,031, and silver (fine) 5,891,901 oz.

A considerable impulse has been given to the mining industries of Arizona by discoveries made in the Tombstone district, in Cochise County, but the bullion production of that area was only beginning to come forward during the period covered by the tenth census.[4]

The mining district and town of Tombstone are situated in Cochise County, Arizona Territory, at the north-west end of the Mule Pass range of mountains, on the right bank of the San Pedro River, from which the town is nine miles distant. It is also twenty-four miles south of Benson Station on the Southern Pacific Railroad of Arizona, and about forty miles north of the Mexican line. Its

[1] W. Ashburner and W. P. Jenney, *Report on the Ontario Silver Mining Company's Property*, San Francisco, 1881.

[2] O. J. Hollister, *loc. cit.* p. 16.

[3] *The Mineral Industry*, iii. 1894, p. 278.

[4] William P. Blake, F.G.S., "The Geology and Veins of Tombstone, Arizona," *Trans. Amer. Inst. Min. Eng.*, x. 1882, p. 334.

altitude above the sea is approximately 4,600 feet. The Dragoon Mountains rise to the north-east, and the Huachuca Range lies on the south-west. The country is without timber, and the surface where the mines are opened is in general gently rolling and accessible to waggons by natural roads. The first mining grants were made in the year 1878, and in 1882there were probably over one thousand claims taken up in the district and upwards of 2,500 inhabitants. The output of the precious metals, gold and silver, up to January 1st, 1882, amounted to $7,359,200, and over $3,000,000 had been disbursed in dividends.

In going from Benson to the mines the traveller rises from the Post-Pliocene deposits along the San Pedro to a granitic plateau. The rock is gray, and highly crystalline, is apparently eruptive, and weathers into gigantic rounded blocks lying one upon another, as if piled there by some enormous force, and extends to within a mile or two of Tombstone, where stratified formations occur overlying the granite. These stratified beds consist of quartzites, limestones and slates, with frequent repetitions in an ascending series several thousand feet in thickness, but all conformable, and dipping, generally at a low angle, towards the east. The fossils which have been found in the middle and upper beds show them to be Palæozoic and probably of Lower Carboniferous age, whilst the lower strata are probably older.

In addition to the stratified formations there are intrusive porphyritic dykes cutting indiscriminately through the strata nearly at right angles, and trending approximately north and south. This is the direction of the general faulting of the country, and also of the mineral veins. In the central portion of the district, erosion has exposed the outcropping edges of many strata of limestones, shales and quartzites. Both the shale and quartzite beds are very fine-grained and compact in texture, with scarcely any signs of granular structure. The latter is flint-like and hard, and is more exactly described as a novaculite or honestone, passing in places insensibly into siliceous limestone. An abundance of iron pyrites in fine crystalline grains is disseminated through the layers of this rock, which derives special importance from the fact that the mines on the Tough Nut and Good Enough claims find it below the chief ore-bearing limestone. The beds above it consist of dark, black, or blue limestones, and of thick beds of dark argillaceous shale, alternating with black siliceous shales for nearly half a mile to the eastward. The black limestones above the novaculite are the chief repositories of the bedded masses of rich silver ore.

The whole series of beds in this central part of the district is thrown into folds, being regularly plicated in a series of wave-like flexures which may be traced, although with some difficulty, upon the surface, but are best seen in the cross-cuts of the mines and along the drifts. In the open cut upon the Tough Nut there is a good exposure of some of the beds at the crest of an anticlinal fold, presenting an appearance, in section along a north-east and south-west cut, as shown in Fig. 119 in which *a* is novaculite, under the limestone, *b* limestone bending over the novaculite, and *c* shales over the limestone.

This section is along the upper level known as the adit, and is directly below the place on the surface where ore was found cropping out mixed with soil and vein-stuff. At another place there is a series of plications, at about the angles shown with rich ore

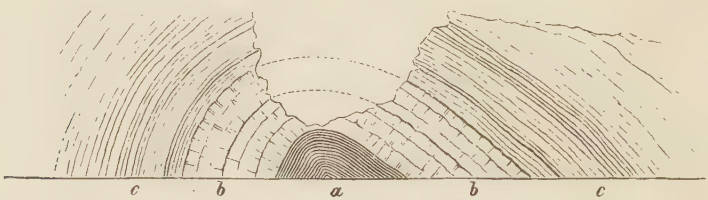


FIG. 119.—Anticlinal, Tough Nut claim

lying in the folds. These folds are not large, covering a few hundred feet in extent only, but are beautifully regular and well-defined; in the series of strata to the eastward the dip becomes more regular, coarse-grained quartzites, in thicker beds, taking the place of finer-grained deposits. All the formations named have not only been uplifted as described, but have been much broken and faulted either at the time of uplifting or subsequently.

The chief ore-bearing vein of the district traverses the Grand Central and the Contention claims. These were laid out in a north and south direction upon the somewhat obscure outcrop of a dyke of dioritic porphyry carrying ore in, through, and alongside it. The outcrop was not well-defined, consisting of porphyry and of a confused mixture of porphyry, chert and quartz, with masses of porous quartzite alongside, none of the rocks rising high above the soil. There was, however, a considerable discoloration by oxide of iron, and a small amount of digging revealed good ore near the surface. This dyke varies in width from a few feet to seventy feet, and dips to the westward at an angle of from 55° to 65°. It cuts indiscriminately through shales, quartzites and limestones, and is evidently of igneous origin. Its contact, however, with the abutting edges of the disrupted beds is not always marked by any material change in their appearance or composition, although in places there is obscure metamorphism, and some slight modification of structure. The dyke itself has a distinct vertical lamination, and is more or less penetrated by thin veins of quartz. In some portions it is highly crystalline, whilst in others it consists, chiefly, of a felspathic base in which the felspar crystals are obscure. It finally passes into a felsite, which, in the decomposed portions of the dyke, and when slaty in structure, might be mistaken for altered shale or quartzite. Large portions of the dyke are so penetrated by quartz as to consist largely of that mineral, although close examination shows the presence of felspar.

There is also a considerable amount of mineralisation of the dyke by iron pyrites disseminated irregularly in cubical crystals, most of which have been dissolved out and left cavities only to indicate their former presence, giving rise in places to a spongy mass of either porphyry or quartz. Although the mines have been worked to a depth of 600 feet and there are some twelve to fifteen miles of drifts, levels, and winzes in the Contention and adjoining mines, the undecomposed ores below the water-level have not been reached, and all the minerals above that point are in the decomposed and oxidised condition common to surface ores. A large portion of them is charged with red oxide of iron to such an extent that the clothing of the miners becomes saturated with the rouge-like powder, and the tailings at the mills are blood-red in colour.

There has been an extensive decomposition of the porphyry along the upper 300 feet of the dyke, resulting in the formation of quantities of kaolin, sometimes perfectly white and pure, but generally more or less stained by red oxide of iron. This kaolinisation extends in places to the adjoining shales, and there are some white, clay-like interstratified beds, which may, on further examination, be found to be altered felsitic offshoots from the dyke. The only metalliferous contents, with the exception of the pyrites and some galena and lead carbonate, are gold and silver in a partially free state, part of the gold, if not all of it, being free, the silver occurring chiefly as chloride, with probably some iodide. The average value of gold and silver in the ores worked in 1880 was about $70 per ton. The gold represents from 20 to 25 per cent. of the value of the product, the remainder being silver. A very interesting fact is the occurrence of metallic gold, together with chloride of silver, disseminated in the midst of the porphyritic rock, at a distance of many feet from the portions of the porphyry carrying quartz in veins. This gold is found chiefly in a portion of the rock containing finely-disseminated hornblende. In decomposing, this porphyry becomes steatitic, and in places appears to be changing to serpentine. The gold is found in thin sub-crystalline flakes and scales, chiefly in and along thin seams and cracks in the mass of the rock, as if it had been infiltrated and deposited from solution. Free gold is also found in quartz in the usual manner of association; but even in such specimens the crystalline felspar of the dyke is also found.

The whole of the dyke, together with the adjoining strata, has been subjected to extensive movements and displacements, shown not only by breaks of continuity, but by brecciated cross-courses and by seams traversing both the igneous and stratified formations. This disruption of the dyke, with its attendant fracturing and brecciation of the country rock, accompanied by the movement of the dyke upon itself, and the formation of heavy clay seams, has provided suitable places for the accumulation of ore, which is generally found in the softer and more broken portions of the dyke. The only place upon the lode where water has been reached is upon the Sulphuret claim. At this point the lode intersects limestone, and there is a bedded layer of ore following the stratification and connected with the dyke; this ore is chiefly galena and iron pyrites. Bedded ore deposits are associated with bedded dykes, and with vertical fissures nearly parallel with the Contention Lode. One of the longest and best defined is the West-side Lode, which may be traced for about two miles, until it passes into the underlying granite.

A line of fissure cuts across the anticlinal line of the formations at the open cut on the Tough Nut, and crosses the whole breadth of the Good Enough into the claim beyond. This has been followed on ore from the open cut, and is connected with the chief lateral bedded deposits. A lode has also been followed in the same general direction from the claim called the Defence across the Tough Nut into the Good Enough. This lode is marked by heavy outcrops of quartz, and by flinty boulders lying above the limestone on the surface.

The bedded offshoots from the vein, which are often of considerable lateral extent, following the planes of stratification on either side, may be due to the decomposition of nodular masses, but they are generally deposited in the limestone as if by replacement. They may be regarded as filling irregular cavernous spaces eroded in the strata by metalliferous solutions, and are without any regular boundaries. The bedded masses do not exhibit a symmetrical arrangement of the ore, except such as may be referred to stratification or deposition by gravity. It is to be observed that the bedded masses of ore occupy the limestone rather than the siliceous or argillaceous strata, as might be expected from the greater solubility of limestone. In extent the bedded masses have been much larger than the ore bodies of the vertical fissures, and it may be said that the larger portion of the production has been from beds or flats. They extend irregularly between two fissures, for a distance of about 400 feet measured diagonally along the dip. It is noteworthy that they follow the stratification for some distance and then suddenly break across it vertically, following a crack or break in the bedding, and then again expand horizontally for some distance to another crack, when they drop down by a series of steps from one layer to another between the limestones. The ores found in these bedded deposits in limestone are much more plumbiferous than is the ore of the felspathic dyke. Galena, blende and iron pyrites are abundant in masses, which, within the reach of oxidising agencies, are largely converted into oxides and carbonates. The similarity between this mode of occurrence and that of more or less argentiferous lead ores in other countries (*e.g.*, the flats of the North of England lead mines) is sufficiently obvious.

The Castle Dome district lies in the foot-hills, and on the western slope of a range of mountains, in Arizona, eighteen miles east of Castle Dome Landing, on the Colorado River. The district, as already traced, is two miles in width and seven in length, following the trend of the mountains. The lodes in this district were rediscovered in the year 1863, but it is evident that they had been opened and worked, to a shallow depth, at a comparatively remote period, probably by some of the Spanish priests who first made their way from Mexico into Arizona. The ore, which occurs in true veins, is a dense brilliant galena, carrying about 30 oz. of silver per ton. The rocks of this region are compact fine-grained mica schists and clay slates, standing nearly on edge, and traversed by numerous porphyritic dykes, which apparently bear some close relation to the mineralisation of the veins. The veins have a general north-west and south-east course, their outcrops being made chiefly evident by fragmentary crystals of rose-coloured fluor spar, which constitutes the chief veinstone accompanying the galena, and which forms an excellent flux for the ore. This is the only known instance of the general occurrence of fluor spar in lead-bearing veins in the United States. Calcite and gypsum are also often present, and in some of the veins quartz constitutes an important portion of the gangue, being either arranged as combs parallel to the walls, or forming sheets in the middle of the veins.

During the first six months of the year 1879 the shipments to San Francisco, where the works of the company are situated, amounted to 438½ tons of ore, yielding $21,367, or an average of $48 per ton of 2,000 lbs. The average percentage of lead was 69, and the contents of silver 26 oz. per ton. The value of the lead per ton was $25·61, and the value of the silver at 90 cents per oz. $23·89 per ton of ore, making a total of $49·50 per ton of ore.[1]

The total production of Arizona during the tenth census year was estimated at $211,966 for gold and $2,325,826 for silver, and consequently the yield of the latter is much in excess of that of gold. Mr. King, however, states that, from not being in some cases furnished with the necessary returns, the above estimate may possibly be wrong to the extent of some 20 per cent. During the eleventh census year the production was 44,029 oz. of fine gold worth $910,174 and 1,812,961 oz. of fine silver worth $2,343,977. In 1894,[2] according to the *Mineral Industry*, the figures were: gold 96,313 oz., worth $1,990,966, silver 1,539,453 oz.

The gold production of Idaho during the tenth census year amounted to $1,479,655, of which 59·42 per cent. was the yield of placers, and 40·58 per cent. the result of deep mining; the production of silver for the same year amounted to only $464,550. The principal mining areas are those of Owyhee, the New River country, and the Yankee Fork region. During the eleventh census year the State produced: fine gold 95,893 oz., worth $1,984,159, fine silver 3,137,508 oz., worth $4,056,482. The silver is obtained principally from deposits of argentiferous galena and blende in limestone rocks in the southern part of the State, and from the Poorman Lode, a fissure vein apparently in porphyry and metamorphic rocks, carrying ruby silver and other silver ores. In 1894[3] the output of the State was: fine gold 100,682 oz., value $2,081,281, fine silver 3,288,548 oz.

[1] W. P. Blake, *Report to Castle Dome Mining and Smelting Company*, July, 1880.

[2] *The Mineral Industry*, iii. 1894, p. 278.

[3] *Ibid.*

Oregon is one of the oldest of the western mining States, the finding of gold within its boundaries having closely followed the discovery of that metal in California. Its yield was never large in comparison with that of the neighbouring State, but, although the mines have now become secondary to its agricultural resources, they still afford remunerative employment to many of its inhabitants. The quartz veins of the portion of the State which adjoins Idaho continue to yield the greater portion of the total deep-mine production of the country. The prevailing type of the ore is an easily-worked auriferous quartz, although rebellious gold ores, requiring special treatment, are found in some localities, and a small amount of silver is produced in Grant County. This county also takes the lead in placer mining, while Baker, Jackson and Josephine counties also furnish a considerable amount of alluvial gold. The production of the precious metals in Oregon during the year ending May 31st, 1880, was: gold $1,097,700, silver $27,793. In 1894 [1] it was: fine gold 68,792 oz., value $1,422,056, fine silver 26,171 oz.

Of the comparatively small production of the deep mines of Washington Territory, by far the larger portion comes from the Peshastin district, in Yakima County, where quartz mining is carried on upon a limited scale. The Upper Columbia placers furnish above one-half of the alluvial gold annually obtained in the Territory. The yield of the precious metals during the year 1880 amounted, according to official returns, to: gold $135,800, silver $1,019. In 1894 [2] it was: fine gold 9,438 oz., value $195,100, and fine silver 113,160 oz.

The vast region of Alaska, occupying an area of half a million square miles, remains in large part still unexplored, whilst its exceptionally severe climate, and its remoteness from facilities of communication, must always remain obstacles to the development of its mines.

Several placer districts are known, amongst which those of Takou district rank as about the most productive. A mineralised belt [3] seems to extend for about a hundred miles, with a width of from one to several miles, running in a north-westerly direction, close to the western seaboard of the Territory. The belt is mostly characterised by granites, slates, serpentines,

[1] *The Mineral Industry*, iii. 1894, p. 278.

[2] *Ibid.*

[3] G. W. Garside, "The Mineral Resources of Southern Alaska," *Trans. Amer. Inst. Min. Eng.* xxi. 1892, p. 815.

porphyries, and other igneous and highly metamorphic rocks, traversed by veins of quartz carrying gold and ores of silver, lead, copper, zinc, &c., the gold being generally associated with iron pyrites. By far the most important deposit is that known as the Paris or Treadwell Mine, worked by the Alaska-Treadwell Gold Mining Company, on the eastern side of Douglas Island, which is separated from the mainland by a channel less than a mile in width. This deposit seems to consist of a mass of highly altered granite,[1] interpenetrated by veinlets of quartz and mineralised by gold and auriferous iron pyrites. This mass of granite seems to be a boss or dyke, some 420 feet in width, that has broken here through slates of apparently Triassic age.

It has been followed down to 220 feet below adit level, where it seems to be assuming the form of a vein or dyke; a large "horse" of slate rock has been cut in depth. The altered granitic rock consists of quartz, felspar, calcite and pyrites, containing kernels of unaltered granite. There seems to be evidence that the granite had undergone considerable crushing action which probably rendered it permeable by the mineralising solutions that brought in the gold and the pyrites. In the twelve months ending May 15th, 1895,[2] there were mined and treated 241,278 tons of ore which yielded free gold to the value of $411,070 and 4,233 tons of pyrites, which produced gold to the value of $215,256. The total yield was therefore at the rate of $2·60 per ton of which $0·70 was free gold; the concentrates, of which the ore carried about 1·75 per cent., yielded at the rate of $50·51 per ton. From the commencement of operations in 1882 to the end of May, 1895, there were treated 1,775,987 tons of ore which produced $4,334,591 worth of free gold and $1,508,525 worth of gold from 34,802 tons of concentrates, or total of $5,843,116, being at the rate of $3·40 per ton. Out of the above total, profits to the amount of $2,980,286 were obtained, an exceptionally good return upon such low grade ore.

A somewhat similar deposit has recently been opened in the neighbouring Alaska-Mexican Company's Mine. The deposit, which is spoken of as a "vein" by the miners, is probably a narrow dyke; its width [3] at the 220-foot level is 22 feet. In the upper levels it has been driven on for a length of 720 feet and is 40 feet wide in places. During the year 1895 there were crushed 79,439

[1] J. F. Kemp, *Ore Deposits of the United States*, 1893, p. 254.

[2] *Fifth Annual Statement of the Alaska-Treadwell Gold Mining Company.*

[3] *Third Annual Statement of the Alaska-Mexican Gold Mining Company.*

tons yielding $155,638 worth of free gold, being at the rate of $1·96 per ton, and $70,620 worth of gold from the concentrates, or a total of $226,258, being at the rate of $2·85 per ton. There were obtained 1,597 tons of concentrates (about 2 per cent.) yielding at the rate of $44·83 per ton.

According to official returns the total production of Alaska during the tenth census year was: gold $5,951, silver $51. In 1894[1] it was: fine gold 53,868 oz., value $1,113,550, and fine silver 22,261 oz.

The total production of the Pacific Division of the United States during the tenth census year amounted to: gold $25,261,828, silver, $21,143,881. In 1894[2] it was: fine gold 1,099,838 oz., value $22,732,084, fine silver 12,388,599 oz., value $7,804,818.

Division of the Rocky Mountains.—The division of the Rocky Mountains comprehends Colorado, Dakota, Montana, New Mexico, and Wyoming. This division yields about one-fourth of the gold and one-half of the silver annually produced in the United States; in addition to which, a large proportion of the lead produced in the country is obtained from the mines of this region.

From an average annual production of between three and four millions of dollars, Colorado has suddenly risen to the first rank among the States and Territories as a producer of mixed bullion, of which the larger proportion is silver. As a gold-producing State it occupied the fourth place in 1880, was second in 1894, and as far as returns are available but little behind California in 1895, in which year its production is estimated at close on $15,000,000, or only about 4 per cent. less than that of California. The most important mining area in the State of Colorado has been that in the vicinity of Leadville, a town situated in Lake County, on the western flank of the Mosquito or Park range of mountains, and on the eastern slope of the valley of the Arkansas, at a mean average elevation of 10,150 feet above the level of the sea. The Rocky Mountain Chain is here composed of three more or less parallel ranges; the Colorado or Front Range, the Mosquito or Park Range, and the Sawatch Range. The Arkansas Valley is a meridional depression about sixty miles in length by sixteen in width, bordered by the sharp peaks of the Mosquito Range on the east, and by the equally high but broader mountain mass of the Sawatch Range on the west. At a distance of about twenty miles from its head the foot-hills of the bordering ranges close together,

[1] *The Mineral Industry*, iii. 1894, p. 278.
[2] *Ibid.*

confining the present bed of the stream within a narrow rocky cañon, a few miles above the town of Granite.

On the upper edge of a gently-sloping terrace, between Big Evans and California Gulches, and at the base of Carbonate Hill, the extremity of a western spur of the Mosquito Range, is situated the city of Leadville. Gold was first discovered in 1859 on Tarryall Creek, at the head of the South Park, and early in the spring of 1860 two parties of prospectors stumbled almost simultaneously upon rich diggings in California Gulch, near the present site of Leadville. Large quantities of alluvial gold were obtained from this gulch, and a town was built along its banks, known as Oro City; the richer placers, however, became rapidly exhausted, and in the course of three or four years the population of the town of Oro had become reduced from thousands to hundreds. The miners of that date, who had acquired their experience in the gold-fields of California, knew little or nothing about the ores of silver, but prospecting for gold was to some extent carried on upon the outcrops from which the gold of the placer diggings had been derived. These operations resulted in the discovery of several gold mines which, for a time, brought back a gleam of renewed prosperity to the dwindling camp at Oro, but of whose yield no data are available. Few, however, if any, suspected the value of the so-called "heavy rock," fragments of iron-stained carbonate of lead, which, being too heavy to be carried off by the force of running water, obstructed the sluices and required to be removed by hand.

The practical discovery of the argentiferous ores of Leadville was, however, made in 1875, and the first small lot was shipped to Saint Louis in 1878. Active prospecting over the whole region commenced in the spring of 1877, and the development of rich and productive mines from that time advanced with astonishing rapidity.

The most ancient rocks of the Leadville district are of Archæan age, consisting of granite and gneiss, above which follow successively Cambrian quartzites, Silurian white limestones, Carboniferous blue limestones and grits, and finally Quarternary deposits consisting of lake beds and post-glacial drifts. The igneous rocks of the district comprehend different varieties of porphyry, and the strata are traversed by numerous faults, which in some places represent considerable displacements. Throughout this region the stratum of dark blue, often nearly black, limestone, at the base of the Carboniferous formation, is the most important ore-bearing rock. There are, however, other horizons in which ore is sometimes found, although in general in masses far inferior in quality and extent to those occurring at the contact of this limestone with the porphyry, which almost everywhere overlies it. The ore is principally argentiferous galena, with its products of alteration, cerrusite and chloride of silver, whilst, as accessory minerals, anglesite, pyromorphite, minium, blende and calamine are sometimes met with. Native sulphur has occasionally been found as a result of the decomposition of galena, as well as metallic silver, produced by the reduction of the chloride of that metal.

Mr. S. F. Emmons, of the United States Geological Survey, was for some time engaged in a study of the structural and mining geology of the district about Leadville, and material was gathered for an exhaustive monographic report on the geology and mining industry of the locality. In an abstract of this report, published in 1882, Mr. Emmons[1] remarks that, although his conclusions cannot claim the merit of great scientific originality, since similar opinions have already been put forth by investigators in other fields, they have been arrived at purely from an impartial study of the peculiar conditions of the district, without any pre-conceived theory which might tend, unconsciously, to bias the opinions of the observer. The most important facts observed and conclusions arrived at bearing upon the formation of these metalliferous deposits are :—

1st. "The occurrence, on an enormous scale, of intrusive bodies of eruptive rock of Secondary or Mesozoic age, and of exceptionally crystalline structure, which are so regularly interstratified as to form an integral part of the sedimentary series ; and yet which never reach the surface, but were spread out and consolidated before the great dynamic movement or mountain-building period at the close of the Cretaceous.

2nd. "That the original ore deposition took place after the intrusion of the eruptive rocks, and before the folding and faulting occasioned by the great dynamic movement.

3rd. "The minerals contained in the principal ore deposits of the region were derived from circulating waters, which in their passage through the various bodies of eruptive rocks took up certain metals in solution ; and, concentrating along bedding-planes by a metamorphic or pseudomorphic action of replace-

[1] "Abstract of Report on Geology and Mining Industry of Leadville," *Annual Report of the Secretary of the Interior*, iii. 1882, p. 203.

ment, deposited these metals as sulphides along the contact or upper surface, and to greater or less depth below that surface, of beds generally of limestone or dolomite, but sometimes also of siliceous rocks.

4th. "That in the region immediately about Leadville the principal deposition of silver-bearing minerals took place at the horizon of the lowest member of the Carboniferous group, the Blue limestone formation, commencing at its contact with the overlying White porphyry. But that, while this particular formation has been peculiarly susceptible to the action of ore currents in this region, it is not admissible to assume, as some have done, that in general the beds of any one geological epoch are more favourable than those of any other to the formation of this important type of silver-bearing deposits; since, although they are generally found in greatest abundance in calcareous beds of Palæozoic age, the horizon of such beds is by no means identical in the various mining districts in which they have been thus far developed.

5th. "That in this, as in many other mining districts, dykes of eruptive rock, cutting the ore-bearing formation transversely, seem to favour the concentration of rich ore bodies or bonanzas in their vicinity.

6th. "That on fault planes, on the other hand, no considerable ore bodies have been deposited, as might have been assumed, *a priori*, from the fact that their origin is later than that of the original ore deposits."

On the other hand, Mr. J. Alden Smith, the State Geologist of Colorado, says in his report on the mineral resources of Colorado:[1]—"I am impelled to reiterate the opinions heretofore expressed, that the ore deposits of this district came from below through fissures originating in the granite rocks, and, extended upward, penetrated the limestones and quartzites to the contact with the overlying porphyry; that these fissures lead to many bedded veins in the limestone or quartzite, and to contact veins of more or less value between the formations last mentioned, and between those and the granitic formation; and that these fissures and deposits will be extensively and profitably worked for centuries after the contact deposits now operated on are exhausted."

[1] *Report on the Development of the Mineral, Metallurgical, Agricultural, Pastoral and other Resources of Colorado for the years* 1881 *and* 1882, Denver, 1883, p. 69.

The *Leadville Herald* states that the metallic production of Leadville for the year 1881 was $13,170,576. The statement of the year's yield made up by the *Leadville Democrat*, shows a less production. It states that, from ore supplied by 131 mines, 7,174,234 oz. of silver and 11,135 oz. of gold were obtained, together with 37,204 tons of lead, representing a value of $13,100,761. This, however, omits the gold production of the gulch mines, reported at $69,000, which, added to the total, brings the product to $13,169,761, or within $815 of the *Herald's* estimate. It is uncertain which is correct, but from these estimates it may be deduced that the production of Leadville in 1881 was about: gold $300,000, silver $10,300,000.[1]

The Bassick Mine, which is situated six miles east of Silver Cliff, in Custer County, has always exhibited such very peculiar features as to render it one of the most remarkable in Colorado. It is situated near the centre of a small rounded hill, composed of trachyte and felspathic conglomerate, of which the greatest diameter is, at its base, about 1,200 feet, whilst its height above the general level of the surrounding country does not exceed 200 feet.

Mr. L. R. Grabill,[2] who has described this remarkable deposit, states that an outcrop of fine-grained conglomerate is exposed on the south-west side, whilst on the north-east the hill joins, by an upward slope, the fine-grained felspathic rock of Mount Tyndall, which rises some 600 feet higher, and of which the elevation containing the Bassick Mine forms an arm.

On visiting this mine attention is immediately attracted by the unusual method of arrangement of the ore, which is seen to be disposed in concentric layers around fragments of trachyte. These fragments, each of which constitutes a nucleus for a concentric arrangement of deposits, vary in size from boulders having a diameter of two feet to pebbles whose diameter is not greater than half an inch. These have no sharp or rough edges, but have evidently been much worn by friction before the deposit of the metalliferous minerals took place, their shape being usually approximately spherical. They consist of trachyte precisely similar in character to that of the country rock, of which they are without doubt a portion. These, with their coatings of ore, quartz,

[1] *Report of the Director of the Mint upon the Production of Precious Metals in the U.S.*, Washington, 1882, p. 416.

[2] "On the Peculiar Features of the Bassick Mine," *Trans. Amer. Inst. Min. Eng.*, xi. 1882, p. 110.

and kaolin, constitute the greater portion of the filling of the fissure, and when separated from the surrounding layers of ore they rarely show by assay anything beyond a trace of the precious metals.

As before stated, around each of these water-worn fragments, as a nucleus, are arranged concentric layers of ore, each particular mineral forming a separate stratum. The layers always follow one another in the same order, are of about the same proportionate thickness, and are all parallel to the surface of the nucleus. Usually three, but sometimes four, distinct layers are seen firmly attached to one another, but with the line of separation perfectly visible. The stratum next the nucleus, which is invariably the thinnest, consists of sulphides of zinc, antimony and lead; this layer varies from the thickness of a sheet of paper, in the outer portion of the ore body, to some two and a half inches nearer its centre, but is usually from $\frac{1}{60}$ to $\frac{1}{30}$ inch through. This stratum contains about 60 oz. of silver per ton and from 1 to 3 oz. of gold, but varies much in composition. Next to this coating a second is often found, which, although it is not always very distinct, is lighter in colour, slightly thicker, and contains more lead, silver and gold than the previous one. This coating frequently contains as much as 100 oz. of gold per ton, and from 150 to 200 oz. of silver. The third shell, counting from the nucleus outwards, consists of blende from a quarter of an inch to two and a half inches thick; this mineral, which is usually crystalline, generally contains from 60 to 120 oz. of silver per ton, with from 15 to 50 oz. of gold, and constitutes the principal source of value in the mine. It contains also a considerable amount of iron and copper sulphides. The inner surface is smooth, but the outer is rough, with the points of the crystals projecting. The fourth coating, when there is one, is formed of chalcopyrite, and varies much in quantity. Sometimes it consists merely of crystals, sparsely scattered over the rough pointed surface of the blende, whilst at others it attains a thickness of three-quarters of an inch. This contains as much as 100 oz. of gold per ton, and about the same amount of silver. Outside of this there is occasionally, though rarely, a fifth thin coating or sprinkling of crystalline iron pyrites.

Surrounding all, especially in the larger cavities, but not usually in the smaller ones, nearer the outer edges of the ore body, kaolin is found. This exists, however, not as a coating, but rather as completing the filling of the crevices between the boulders. The fragments of rock which these minerals surround are not necessarily in close contact, nor do they fit into one another in any way; they resemble in general disposition a loose pile of water-worn stones which have been carelessly thrown into a pit, and have afterwards become coated with thin metalliferous coverings. A peculiar fact regarding this deposit, and one which is somewhat difficult to explain, is that the nuclei or barren fragments are rarely in contact with one another, whilst the metalliferous envelopes surrounding them are in immediate contact. Thus, where actual contact between the boulders themselves might be expected, there are frequently found at the point of approximate meeting, two separate layers of ore, one belonging to each of the contiguous nuclei.

The only other mine in the district known to exhibit a concentric arrangement of minerals around a barren nucleus is the Bull-Domingo, seven miles from the Bassick. But there the ores and country rock are different, galena and spathic iron ore having been deposited around a nucleus of syenite, and the ores containing practically no gold.

The fissure, which in itself constitutes one of the peculiarities of the Bassick Mine, is an irregular opening, nearly elliptical in horizontal section, but varying in width, its shorter diameter being sometimes as small as twenty feet, whilst the larger approaches to one hundred. It has been found that for over eight hundred feet its downward direction very closely approaches the vertical; in horizontal direction it has no well-defined outline. There are not, as in ordinary fissures, any signs of a wall of country rock, and no continuations or extensions of the ore body have been found.

The ore is richer towards the centre of the body, the layers, called "scales" by the miners, being there thicker, and contain a larger proportion of the precious metals; but, as the edge is approached, it thins out and gradually becomes poorer, until at last it is too poor to be worked advantageously. From the centre of the body outwards, the fragments decrease in size and the layers of ore become thinner. Continuing the outward course, but without having passed any particular line marking a boundary, a conglomerate is reached, composed of small rounded pebbles of felspathic rock cemented by a hardened trachytic paste, but containing no ore. In the same manner, without finding any defined boundary, the country rock is reached. This is of the ordinary character, is gray in colour, and is of the same nature on all sides of the ore body.

The other products of the mine, occurring in subordinate quantities, are:—calamine, silicate of zinc, jamesonite, tetrahedrite, tellurides of silver and gold, free gold, quartz and graphite. The carbonate of zinc and electric calamine are found only amongst the upper or oxidised ores above the water level, and are doubtless the result of the decomposition of blende. Above the water level most of the free gold is found in wires and other usual forms. Tetrahedrite never occurs as a coating, but always filling vacancies between the coated boulders, and is usually found intermingled with quartz. In the same mass are also tellurides of gold and silver.

The quartz in this mine would appear to be a residue from the decomposition of silicates by impregnating solutions, and is found, like the tetrahedrite, occupying open spaces outside the coated boulders, and never within them, serving to some extent as a cement to hold the mass together. This quartz is, for the most part, amorphous, rarely showing any traces of crystallisation; when it does so it is amethystine, but more frequently it appears to have been deposited in a gelatinous state.

One of the most striking features of this mine is, however, the existence in it of carbonised wood. This is found in cavities between the coated boulders, and toward the outer edges of the ore body, but it is not necessarily adjacent to ore. It does not often occur, but has been found both near the surface and at great depths. Mr. Grabill is inclined to the opinion that this deposit has been the site of a geyser or mineral spring, carrying minerals in solution in its waters. A more recent view is that these ores occupy the vent of an old volcano.[1]

Gilpin County is the smallest in Colorado, but, with the exception of Lake County, has been the most productive of bullion. Its dimensions are somewhat less than fifteen miles by twelve, and its principal gold mines are situated in groups within an area of less than sixteen square miles. Mining was commenced in this area about 1880, and during the period between this date and 1882 the production has been $41,000,000, of which $37,500,000 has been gold, and $3,500,000 silver, the whole constituting more than one-fourth of the entire bullion output of the State, and nearly two-thirds of the gold produced. The geology of many of the mining districts is very simple, the area being generally granitic, with occasional patches and dykes of various eruptive rocks. The granitic series embraces all the forms, from true massive granite

[1] J. F. Kemp, *op. cit.* p. 213.

through the various gneissic rocks, down to highly stratified mica schist. The veins are mainly true fissures, having a strike often approximately north-east and south-west, though there are instances where the strike is either nearly north and south or east and west. Tellurium and tellurides occur in the ores of Boulder County and in various other localities in Colorado.

The following figures give the bullion yields of the principal mining counties in this State during the year 1882:—

Lake County	$17,131,853
Gilpin ,,	2,006,516
Clear Creek ,,	2,001,629
Summit ,,	1,150,000
Custer ,,	705,116

Amongst the more recently opened deposits are those of the Red Mountain district, Ouray County, the leading mines being the Yankee Girl and the Guston.[1] The country rocks are principally igneous, consisting chiefly of andesites, trachytes and diorites. The ores are confined to the andesite which is more or less decomposed, and they occur in the form of irregular deposits, spoken of locally as chimneys, elliptical in plan, and running down vertically or at varying angles; the longer axes of the ellipses coincide with the direction of a series of fractures that traverse the district. It would appear that the andesite was decomposed by solutions that made their way along the planes of fracture, and formed these deposits, possibly metasomatically at certain points; the andesite is impregnated more or less with ores for a certain distance round the deposits. The ores consist of sulphides and sulpharsenides of lead, copper, bismuth and silver, sometimes very rich in silver; in the gangue rhodonite, gypsum, barytes, kaolin and quartz mainly occur. The upper portions of the deposits generally consist of oxidised ores, chiefly carbonate, sulphate and arseniate of lead, oxide of iron, carbonate of bismuth, &c., together with smaller proportions of the sulphide ores; this gossan is, as is often the case, much richer than the sulphide ore met with in depth. (*See also* Fig. 59, page 163.)

A still more recently developed district is that of Cripple Creek in El Paso County. The country consists of granite and gneiss,

[1] T. E. Schwarz, "The Ore Deposits of Red Mountain, Ouray County, Colorado," *Trans. Amer. Inst. Min. Eng.* xviii. 1889, p. 139.

traversed by dykes of igneous rocks of various kinds; the gold deposits seem to consist of andesitic breccia and tuff, impregnated with gold, which is sometimes free, but more often intimately associated with sulphides and tellurides, the latter being the more general mode of occurrence. The following is said to be the approximate output of gold from Cripple Creek for the years 1892 to 1895:—[1]

1892	30,000 ounces.
1893	125,000 ,,
1894	200,000 ,,
1895	400,000 ,,

Assuming these figures to be correct, the output of this district in 1894 will have been almost one-half of that of the entire State, whilst the rapid increase in 1895, already referred to, is ascribed almost entirely to the operations in this district. Whilst there is at present no authoritative information available from disinterested quarters, it seems certain that immense bodies of low grade sulphuret ores have been discovered in this district, which will possibly play an important part in the American gold output for some time to come.

The production of precious metals in Colorado during the tenth census year was: gold $2,699,900, silver $16,549,274. Owing to the great fall since then in the price of silver, attention has been devoted more exclusively to gold mining, and silver has been neglected. In 1894[2] the output was: fine gold 461,969 oz., value $9,549,731, fine silver 23,236,025 oz.

The production of Dakota is almost entirely derived from the region of the Black Hills, and in great part from Lawrence County. Nearly the whole yield is obtained from gold-bearing lodes, the gravel deposits being of very secondary importance, with the exception of certain cement deposits that at one time yielded large amounts of gold (*see* page 25). These cement deposits are especially remarkable, because they represent very ancient placers, occupying the lowest position in the Potsdam Sandstone series and lying upon the eroded edges of Archæan rocks; this ancient placer is generally supposed to have been produced by the degradation of the Archæan

[1] Claude Vautin, "Notes on the Cripple Creek Gold Fields," *Mining Journal*, April 4, 1896.

[2] *The Mineral Industry*, iii. 1894, p. 278.

rocks that contain the Homestake deposits, which must, in that case, have been gold-bearing in Archæan times.[1] At present, however, the bulk of the gold is produced from quartz mines. The gold quartz, which is of low grade, is reduced in amalgamating mills of great size and power, by which a large proportion of the gold present in the rock is extracted. Silver ores were discovered in Dakota almost as early as were those containing gold, but the comparative ease with which the latter can be worked led the miners to neglect, to a great extent, the ores of silver. The principal group of quartz mines is that in the Homestake district, the reputation of which has long been established.

These deposits occupy an area about 6,000 feet long and 2,000 feet broad, known as the "Belt," and occur in Archæan metamorphic schists, whose general strike is N 37° 45′ W., with a dip to the east. The deposits which appear to be lenticular in form, have the same strike as the beds but dip at a rather flatter angle, namely about 45°. Mr. Carpenter (*loc. cit.*) calls them beds, but in view of the fact, stated by him, that their dips are different, this cannot be a strictly correct description; they are probably lenticular veins, following nearly the direction of stratification. Whether their formation was in any way connected with the felsitic dykes that traverse the southern portion of the belt, and once, perhaps, overlay the whole of it, is a matter of conjecture. If this felsite is the same rock as that which once seems to have overflowed the entire area, and the remains of which are found overlying the Potsdam beds between Deadwood and Black-tail gulches, then it is probable that the auriferous deposits were formed long before the outbursts of igneous rock took place. These deposits are sometimes of very large size, having at times exceeded 300 feet in thickness; the ore body in the Golden Star claim measures 350 by 150 feet. They all seem to continue in depth as far as they have yet been worked. Besides quartz, these deposits consist largely of slates and schists impregnated with pyrites; indeed the "Belt" may be described as a zone of highly metamorphosed schists, impregnated with auriferous pyrites and traversed by veins or bed-like, more or less lenticular, masses of quartz, also carrying pyrites and gold. In the Caledonia claims, the ore body is described as a mass of pyritiferous chloritic schist between a hanging wall of phyllite and a foot wall of mica schist. Looking upon all these deposits as a whole, they may fairly be described as a gigantic

[1] F. B. Carpenter, "The Ore Deposits of the Black Hills of Dakota," *Trans. Amer. Inst. Min. Eng.* xvii. 1889, p. 570.

stockwork. The following are the results obtained in 1887 by the leading mines:—[1]

	Tons crushed.	Value of bullion obtained.	Average value per ton.
		$	$
Homestake	243,355	903,407	3·71
Highland	146,013	410,953	2·82
Golden Terra and Father de Smet	216,361	639,229	2·02
Caledonia	73,422	295,816	4·02
Totals	679,151	2,249,405	3·31

The total value of gold obtained from the "Belt" in 1887 was $2,271,341. Although the ore is seen to be decidedly low grade, the enormous bodies of it that exist, and the ease with which it can be mined, have made gold mining on the "Belt" a very profitable industry, although the handling of very large quantities of ore is an indispensable condition of success.

The amounts of gold and silver produced in the Territory, as reported by the Census Bureau, during the year ending May 31st, 1880, was: gold $3,035,846, silver $70,813. Of the total quantity of gold only $47,700 was yielded by placer mines. The production of gold and silver in 1881 is estimated by the Director of the United States Mint to have been $4,000,000. In the eleventh census year (1889) the production was: fine gold 149,533 oz., value $3,091,137, fine silver 104,672 oz., value $135,331, whilst in 1894[2] it was: fine gold 159,594 oz., worth $3,299,100, and fine silver 58,972 oz. The gold production has thus remained exceptionally steady over a long period of years.

Until comparatively recently Montana was entirely isolated from the Eastern States except by a long and tiresome coach journey in winter, or by tedious river navigation during a few months in summer. There is now, however, railroad communication to within seventy miles of Helena, connection being made over the Utah and Northern with the Union and Central Pacific roads at Ogden. Owing to want of facilities for transport, &c.,

[1] H. O. Hofman, "Gold Milling in the Black Hills," *Trans. Amer. Inst. Min. Eng.* xvii. 1889, p. 498.

[2] *The Mineral Industry*, iii. 1894, p. 278.

the mining regions of Montana were for a long time but little known to the outside world, and foreign capital did not readily find its way into the country. Some thirty years ago the richest placer mines known were worked in this State, but until recently quartz mining was prosecuted only in a desultory and an unscientific manner.

In addition to gold, silver and lead, the copper ore sent forward from the numerous mines of Montana forms a very considerable item in the metal markets of the world, and its importance somewhat overshadows that of the precious metals, which—more especially silver—are largely got in connection with the copper. In the neighbourhood of Butte City there are several well-marked silver belts, which seem to have been developed along lines of fissures in granite, perhaps by metasomatic interchange, and to be possibly connected in some way with the dykes of eruptive rock that traverse the granite; the valuable minerals are argentiferous galena, zinc blende and tetrahedrite, gold being also in places associated with the silver-bearing minerals. Ores of manganese appear constantly to accompany those of silver. In the southern part of the State there are also deposits of a more usual type of argentiferous galena and zinc blende in limestone. The production of gold and silver in the State during the year ending May 31st, 1880, was, of the former metal $1,805,768, and of the latter $2,905,066. In 1894[1] Montana produced 176,637 oz. of fine gold, worth $3,651,410, and 12,820,081 oz. of fine silver, being thus second on the list of silver producers in the Union, and third amongst the producers of gold. With respect to the latter metal it seems to occupy a similar position in 1895, although its estimated production, $4,400,000, is far below that of Colorado.

The most important mineral-producing portion of New Mexico hitherto explored is Grant County, situated in the extreme southwestern extremity of the Territory. The first discovery of gold made was in 1859 near Pinos Altos. These placers are represented to have been for some time very rich, and washing upon a small scale is still carried on, but principally by Mexicans. In addition to placer mining, much work has been done upon lodes in the contiguous mountains. The amount of gold produced in this district in 1881 was approximately $25,000, about equally divided between the placer and the quartz mines. Numerous silver mines have for many years been worked, intermittently, in the vicinity of Silver

[1] *The Mineral Industry*, iii. 1894, p. 278.

City, and have, in the aggregate, produced considerable quantities of bullion ; silver mining is not, however, so actively carried on in the district as it appears to have been at one time. The mines in the Georgetown district are reported to be rich in ores of medium grade, and will be worked as soon as the cost of working minerals of that class shall have been sufficiently reduced to admit of their profitable treatment. Some other portions of the county hitherto imperfectly prospected must await the period when exploration in distant portions of the Territory shall have become a less difficult pursuit than it now is.

In addition to Grant County one or both of the precious metals have been produced in Doña Aña, Socorro, Santa Fé, and Colfax counties, and more recently in Sierra County, which now ranks next to Grant County. The annexed table shows the output of gold and silver in New Mexico :—

Bullion Production of New Mexico.

	From date of annexation up to 1881.	During the year 1881.	During the year 1889.	During the year 1894.
	$	$	$	$
Gold	10,350,000	185,000	815,655	567,751
Silver	3,622,000	275,000	1,617,578	398,275
Totals . . .	13,972,000	460,000	2,433,233	966,026

Although Wyoming is surrounded on three of its sides by important mining regions, there are but few developed mines within its boundaries. As far as can be ascertained, the actual production of gold during the tenth census year was confined to Sweetwater County, which yielded gold to the value of about $17,320. During the eleventh census year, 711 oz., valued at $14,512, were produced in the counties of Albany and Fremont. In 1894 the production was said not to be obtainable ; it was certainly small, chiefly from placer mining and a few small quartz mines.

The total production of bullion in the division of the Rocky Mountains during the year ending May 31st, 1880, was: gold $7,878,189, silver $19,917,490. It may be estimated for 1894 as very approximately : gold $17,084,500, silver $23,151,000.

Eastern Division.—This group, which comprehends Virginia, North Carolina, South Carolina, Georgia, Alabama, Tennessee, Maine, Michigan and New Hampshire, although the oldest, is the least productive of the three divisions.[1] The first notice of the discovery of gold in the Southern States occurs in Jefferson's *Notes on Virginia*, in which it is stated that a lump of that metal weighing 17 dwt. had been found near the Rappahannock; and Dayton, in his *View of South Carolina*, published in 1802, mentions the finding of a small piece of gold on Paris's Mountain. In 1799 gold was found in Cabarrus County, North Carolina, and placer washings upon a small scale were carried on both there and in Montgomery County for several years. These operations, which were entirely restricted to the washing of sands and gravels, yielded in addition to gold-dust, several nuggets of considerable size, one of which, found in Cabarrus County, weighed 28 lbs. avoirdupois.

The first United States gold was coined at the Mint in 1825, and from that time up to 1830 four-fifths of the gold coined in the country was of native production. From 1804 to 1827 North Carolina furnished the whole of the gold produced in the United States, amounting to about $110,000, but in 1829 Virginia contributed $2,500, and in the same year South Carolina yielded $3,500. In 1830 Georgia made its first deposit of gold at the Mint, amounting to $212,000. Previous to 1825 all the gold of North Carolina had been obtained from shallow washings, but in that year auriferous veinstone, containing a large amount of gold, was discovered *in situ*, and this had the effect of turning attention from "gravel mines" to "vein mines."

The Appalachian Chain takes its origin in Canada, south-east of the St. Lawrence, and forms a series of mountain ridges extending in a south-westerly direction into Alabama. Its width, which is very variable, is greatest nearest its centre, gradually diminishing towards the ends. It is divided into a number of parallel ridges, and has a total length of some 1,300 miles. Along the south-eastern edge of this series of parallel mountain chains, lies an undulating range of elevations known by different names in the various States through which they pass. In Vermont they are known as the Green Mountains, in New York they are called the Highlands, in Pennsylvania the South Mountains, in Virginia the Blue Ridge, and in North Carolina the Smoky Mountains. This belt, which is composed of metamorphosed rocks of Lower Palæozoic

[1] J. D. Whitney, *Metallic Wealth of the United States*, 1854, pp. 114–134; W. J. Henwood, *Metalliferous Deposits*, Penzance, 1871, pp. 371–384; E. Motz and T. M. Chatard, *The Brewer Gold Mine*, New York, 1880.

age, varies from ten to fifteen miles in width, and contains few distinguishable fossils. Immediately to the south of this lies the auriferous belt, running nearly parallel to the Blue Ridge and apparently of the same geological age. In Virginia the central axis of this band has a direction of N. 32° E., but still further north it follows a line more nearly approaching east and west. Its width, where most developed, on the borders of North and South Carolina, does not exceed seventy miles.

Beyond Maryland the auriferous belt is no longer continuous, detached patches only being, from time to time, met with until Canada is reached, where there is a considerable area containing gold. The rocks throughout the whole of the auriferous belt closely resemble one another, and consist of schists of almost every variety alternating with bands of granite and syenite. The predominating rock is a talcose schist sometimes passing into the chloritic and argillaceous varieties. The talcose schists which predominate in the gold-mining districts of Virginia have usually a reddish colour, are often fissile, and have a general strike of about 30° N. of E. For the most part the laminæ of these rocks are almost vertical, and enclose bed-like veins of quartz, together with masses of granite, syenite and protogine. The gold almost invariably occurs in quartz, which, near the surface, is cellular, and stained either red or brown by the oxidation and removal of iron pyrites, with which the precious metal is often associated. In the immediate proximity of the gold-bearing beds, which strictly conform to the schistose structure of the enclosing rocks, the schists frequently assume a thick lamellar aspect, although in other situations they are usually more fissile. The ore-bearing deposits are, for the most part, composed of an intimate mixture of quartz and slate, in which are sometimes embedded distinct and well-defined masses of either the one or the other. Angular and vein-like bodies of translucent or milk-white quartz, surrounded by a coating of brown or red iron ore, are also occasionally met with. Small quantities of auriferous iron pyrites, magnetite and yellow copper ore, together with a little free gold, are irregularly disseminated through layers of more or less ferruginous quartz, and still more sparingly through the adjoining slaty rocks.

One of the most remarkable auriferous deposits of the States on the Atlantic sea-board is that known as the Brewer Gold Mine, situated on Lynch River, Chesterfield County, South Carolina. The mode of occurrence of the precious metal in this locality will be understood on referring to the accompanying transverse section,

Fig. 120, reduced from a drawing by Professor Lieber.[1] In this section, which represents a length of about three miles, *a* is a dyke of coarse-grained granite, south of which is a band of trachyte, *b*, abutting against the talcose slates, *c*, which contain three distinct and parallel bands of lenticular deposits, *d*, as well as some small branches of barren white quartz ; *e* is clay seen at the Slate Ford while at *f* is the auriferous detrital deposit known as the Old Tanyard. Of these three groups of lenticular veins the two northern ones only have been worked, the third remaining almost in its original condition.

The direction of these veins exactly corresponds both in strike and dip with the bedding of the enclosing slaty rocks, and their breadth varies from twenty to fifty feet. These lenticules consist of a blue hornstone which is seldom found in an undecomposed condition, and is never met with in a fresh state except in the centre of the masses constituting the deposits. The hornstone

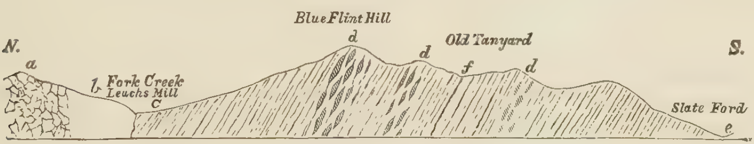


FIG. 120.—The Brewer Gold Mine ; section.

contains finely disseminated iron pyrites and yellow copper ore, by the decomposition of the former of which the disintegration of the mass would appear to have been chiefly effected ; enargite and cassiterite are also present in subordinate quantities. The whole of the hornstone of the lenticular masses at the Brewer Mine is auriferous, but is traversed in every direction by veins of white quartz containing no gold.

The Tanyard, where the first gold was discovered, is an extensive detrital deposit, lying in a valley, and evidently resulting from the disintegration and removal by water of the auriferous lenticules on either side. A shaft and a tunnel, which, according to tradition, were made previous to the War of Independence, are still visible, but the presence of workable gold in this locality appears to have been first made known by Brewer, who discovered it at the Tanyard in the year 1828.

For many years these disintegrated gravels were leased in plots, each usually twelve feet square, which the lessees worked when and

[1] *Report on the Survey of South Carolina*, 1858, p. 63.

in what way they thought proper, paying to the proprietor of the soil a royalty of one-fourth of the gold extracted. The ill-directed labour thus expended was for a long time remunerative to all parties, but the disadvantages arising from such an entire lack of system at length became so great that, some fifteen or twenty years ago, the property was for the first time worked as a whole by the hydraulic system. The discovery of tin ore in the sluice-boxes of this mine is interesting rather on account of the peculiarity of its occurrence than for its commercial value. The crystals of this mineral are often well formed, and are not unfrequently studded with crystalline particles of gold.

According to the report of the Director of the United States Mint, South Carolina suffered in 1881 from a drought, which materially interfered with gold mining generally. The Brewer Mine fully answered expectations and would have produced from $25,000 to $30,000 during the year, had not the lack of water, in the month of August and subsequently, brought the work almost entirely to a standstill.

A typical and an important South Carolina mine is the Haile Mine, in Lancaster County, well-known as being one of the first at which barrel chlorination of gold ores was successfully practised. The country rock here is talcose slate,[1] striking between N.E. and E.N.E., and dipping from 55° to 85° to the N.W. These slates are traversed by numerous diabase dykes, cutting across the formation without apparently dislocating the strata. For a considerable distance from the planes of contact, the slates have been very completely metamorphosed, and the altered zones impregnated with auriferous pyrites, which mineral sometimes forms layers four to six inches thick along the surfaces of contact. These impregnated slates are the objects of the mining operations, one wall of the deposit being formed by the dyke, whilst the other is really non-existent, the rock being mined just as far as it contains payable gold. The rock thus mined for treatment averages from 7 to 9 per cent. of pyrites, and assays about $4·50 [2] per ton, of which about $1·50 is free gold, and the remainder contained in the pyrites, the latter assaying $25 to $35 per ton. The Haile Mine was treating about 80 tons a day in 1890. There are several other similar mines in this region, *e.g.*, the Bumalo and Chase Hill mines, close to the

[1] A. Thies and A. Mezger, "The Geology of the Haile Mine, South Carolina," *Trans. Amer. Inst. Min. Eng.* xix. 1890, p. 595.

[2] A. Thies and W. B. Phillips, "The Thies Process at the Haile Gold Mine," *Trans. Amer. Inst. Min. Eng.* xix. 1890, p. 601.

Haile, the Phœnix Mine in Cabarras County, &c. In some respects these deposits are comparable with those of Witwatersand, South Africa, but they are not characterised by the uniformity that is noticeable in the latter. In South Carolina the effect of the diabase dykes in enriching the strata which they traverse is very evident, but the mode in which this enrichment has acted is not so clear; obviously it may be either mechanical or chemical, or both. The position which this deposit should occupy in a system of classification is difficult to fix; it might be assigned to any one of several classes; morphologically it presents most analogies with a stockwork, genetically with the last class of symphytic deposits. This is, however, a matter of minor importance; we must expect to find deposits that occupy positions intermediate between the various classes in any system of classification that may be adopted.

The output of gold in Carolina for 1894[1] was as follows:—

North Carolina . . .	2,254 oz. fine gold,	value	$46,594
South Carolina . . .	4,733 ,, ,,	,,	97,839
Total	$6,987		$144,433

According to official statistics the production of the gold-fields of the eastern division of the United States amounted, during the year ending May 31st, 1880, to only $239,646; for the eleventh census year (1889) it was approximately $410,000.

The silver production of the Appalachian range, that is to say of the States of Alabama, Georgia, Maryland, North and South Carolina and Virginia is given for the year 1889 as $4,688, out of which North Carolina contributes no less than $3,879. The gold production of this range was, according to the census authorities, $322,949. Expressed in ounces these figures would be as follows:—

Gold	15,624 ounces.
Silver	3,626 ,,
Total bullion . . .	19,250 ,,

The silver forms accordingly 18·8 per cent. of the total bullion production, and is therefore probably derived entirely from the refining of the bullion produced by the gold mines, there being apparently no record of any silver mines, properly so-called, in this region.

The total production of each State and Territory, including the yield of the deep mines from ore raised prior to, but reduced during, the tenth census year, and also the silver contents of placer gold, is given in the following table:—

[1] *The Mineral Industry*, iii. 1894, p. 278.

Table showing the Weight and Value of the Precious Metals Produced in the United States during the Tenth Census Year ending May 31st, 1880.

State or Territory.	Production. Gold.	Production. Silver.	Total Value.	Total Value.
Pacific Division.				
	Oz.	Oz.	$	£ s.
Alaska	288	39	6,002	1,200 8
Arizona	10,254	1,798,921	2,537,792	507,558 8
California	829,676	890,159	18,301,840	3,660,368 0
Idaho	71,578	359,309	1,944,205	388,841 0
Nevada	236,468	9,614,562	17,318,913	3,463,782 12
Oregon	53,101	21,497	1,125,493	225,098 12
Utah	14,106	3,668,564	5,034,645	1,006,929 0
Washington	6,569	788	136,819	27,363 16
Totals	1,222,040	16,353,839	46,405,709	9,281,141 16
Division of the Rocky Mountains.				
Colorado	130,608	12,800,119	19,249,174	3,849,834 16
Dakota	159,920	54,770	3,376,659	675,331 16
Montana	87,354	2,246,939	4,710,834	942,166 16
New Mexico	2,387	303,455	441,691	88,338 4
Wyoming	838	—	17,321	3,464 4
Totals	381,107	15,405,283	27,795,679	5,559,135 16
Eastern Division.				
Alabama	63	—	1,300	260 0
Georgia	3,920	257	81,362	16,272 8
Maine	145	5,569	10,200	2,040 0
Michigan	—	20,000	25,858	5,171 12
New Hampshire	532	12,375	27,000	5,400 0
North Carolina	5,755	108	119,095	23,819 0
South Carolina	631	43	13,097	2,619 8
Tennessee	97	—	1,998	399 12
Virginia	451	—	9,322	1,864 8
Totals	11,594	38,352	289,232	57,846 8
Summary.				
Pacific Division	1,222,040	16,353,839	46,405,709	9,281,141 16
Division of the Rocky Mountains	381,107	15,405,283	27,795,679	5,559,135 16
Eastern Division	11,594	38,352	289,232	57,846 8
Totals	1,614,741	31,797,474	74,490,620	14,898,124 0

The following table shows the outputs of the United States for the eleventh census year, 1889,[1] and for 1894 :—[2]

TABLE SHOWING THE WEIGHT AND VALUE OF THE PRECIOUS METALS PRODUCED IN THE UNITED STATES DURING THE YEARS 1889 AND 1894.

States and Territories.	1889.				1894.			
	Gold.		Silver.		Gold.		Silver.	
	Fine. Oz.	$	Fine. Oz.	$	Fine. Oz.	$	Fine. Oz.	$
Alabama . . .	128	2,539	77	100	—	—	—	—
Alaska	43,762	904,650	9,219	11,918	53,868	1,113,550	22,261	14,024
Arizona . . .	44,029	910,174	1,812,961	2,343,977	96,313	1,990,966	1,539,453	969,855
California . .	608,882	12,586,722	1,062,578	1,373,807	673,707	13.923,282	471,955	297,332
Colorado . . .	187,881	3,883,859	18,375,551	23,757,751	461,969	9,549,731	23,236,025	14,638,696
Georgia . . .	5,204	107,605	359	464	4,728	97,736	325	205
Idaho	95,983	1,984,159	3,137,508	4,056,482	100,682	2,081,281	3,288,548	2,071,785
Maryland . . .	501	10,369	—	—	—	—	—	—
Michigan . . .	4,210	87,040	14,607	18,885	2,150	44,444	35,122	22,127
Montana . . .	151,861	3,139,327	13,511,455	17,468,960	176,637	3,651,410	12,820,081	8,076,651
Nevada	169,617	3,506,295	4,696,605	6,072,241	55,042	1,137,819	1,035,151	652,145
New Mexico .	39,457	815,655	1,251,124	1,617,578	27,465	567,751	632,183	398,275
North Carolina	7,077	146,795	3,000	3,879	2,254	46,594	352	222
Oregon	46,648	964,309	17,851	23,382	68,792	1,422,056	26,171	16,488
South Carolina	2,266	46,853	179	232	4,733	97,839	305	192
South Dakota .	149,533	3,091,137	104,672	135,331	159,594	3,299,100	58,973	37,153
Texas	330	6,828	323,438	418,173	—	—	429,314	270,468
Utah	23,591	487,666	7,005,193	9,057,014	41,991	868,031	5,891,901	3,711,898
Virginia . . .	198	4,100	10	13	—	—	—	—
Washington .	9,005	186,150	28,464	36,801	9,438	195,100	113,160	71,290
Wyoming . . .	711	14,512	—	—	—	—	—	—
Other States .	—	—	—	—	1,495	30,903	182	115
Totals	1,590,869	32,886,744	51,354,851	66,396,988	1,940,858	40,117,593	49,601,462	31,248,921

For 1895, the gold output of the United States is stated approximately at $53,114,500.

QUICKSILVER.

The production of quicksilver in the United States is practically confined to California. A few flasks are at times produced in Oregon, and ores of mercury are found in Utah and a few other States, but none of these deposits have any importance at all, especially when compared with those of California.

The quicksilver-bearing belt of California[3] extends over a distance, in a general north and south direction, of about three hundred miles, and is occupied by massive beds of slate accom-

[1] *Eleventh Census of the United States*, "Mineral Industries," 1890, p. 59.

[2] *The Mineral Industry for* 1894, p. 278.

[3] R. W. Raymond, *Statistics of Mines and Mining*, 1874, p. 379 ; *ibid.* 1875, p. 13.

panied by gabbros, or by calcareous and siliceous beds, and is broken through and not unfrequently capped by eruptive rocks. Wherever they come to the surface, these slates are found to be generally more or less impregnated with mercury, either in the form of cinnabar, or in the native state. Selenide of mercury is also occasionally found. These slates extend from San Luis Obispo to the north of Sonoma, and re-appear in Trinity County. Accompanying them, on the south, are calcareous and magnesian rocks of various ages, whilst at the north, and towards the centre, are sandstones and serpentines. Throughout this band, which is sometimes above half a mile in width, quicksilver ores occur as impregnations in the calcareous and siliceous rocks, and as beds or deposits in the slates. The distinction between impregnations and beds is not, however, always well-defined, since many of them might, apparently, be the result either of sublimation or of infiltration. Mercury has been worked as far south as the County of San Luis Obispo, where the most massive ore is found in compact talcose slate, hornstone, and greenstone. The cinnabar is accompanied by much iron pyrites, and is distinctly crystalline.

The New Almaden Mines, in Santa Clara County, are worked upon a number of deposits enclosed, chiefly, in a belt of altered slates, with lenticular masses of serpentine lying on either side. These slates belong to the Neocomian age, but in California the occurrence of cinnabar is not confined to any particular geological horizon.

A rhyolite dyke [1] runs nearly parallel to the line connecting the New Almaden and the Guadalupe deposits, and appears to have had an important genetic relationship with the ore deposits, which generally run parallel to it. The age of this dyke is comparatively recent (? Post-pliocene) and the deposition of the cinnabar would seem to have taken place at no great interval after the eruption of the rhyolite. The commonest type of the ore deposits is a stockwork, or mass of rock that has been impregnated by particles and traversed by veinlets of cinnabar. The rock thus altered shows clear evidence of faulting and shattering; layers of clay produced by attrition of the rocks are often found on the hanging walls of the deposits and are called *altas* by the miners. These clays are not permeable to the solutions which would readily penetrate the shattered rock and they thus limit the formation of the deposits. Well marked slickensides are plentiful. The various ore bodies follow

[1] *Eleventh Census of the United States*, 1890, p. 203.

the direction of two main fissures, running south-east and north-west, parallel to the rhyolite dyke, and in these the ore bodies form well-marked chutes, which have been followed down to a depth of over 2,000 feet. Several subordinate deposits, such as the Cora Blanca, Washington and Enriquita, have no direct connection with those of the main line. The last-named presents a series of irregular bodies and seams of cinnabar occurring through a space some 500 feet long and 60 feet wide, in siliceous limestone enclosed on either side in serpentine.

The New Idria Mines, in Fresno County, consist of a number of workings distributed along a course some three miles in extent between San Carlos and New Idria proper. At the San Carlos workings the rock is a whitish granular sandstone, sometimes in its original condition, but, more frequently, to some extent metamorphosed, through which the cinnabar is irregularly diffused without any apparent system or order. At the Aurora, lying between the San Carlos and the New Idria Mines, the rock is hard and siliceous, frequently coloured by iron, and containing occasional specks of cinnabar. At New Idria proper the rocks are exceedingly varied, but consist chiefly of sandstones and slates in different stages of metamorphism. In one of the main tunnels of this mine the rock is a dark, somewhat bituminous slate, much fractured, exhibiting numerous slickensides, and so disturbed that it is impossible to determine either its average dip or direction. In other parts of the excavations the rock is very siliceous and is broken into a sort of breccia, cemented by the cinnabar, which fills the spaces between the fragments.

At p. 115, I (J.A. P.) have mentioned the occurrence of cinnabar and sulphur at the Sulphur Bank, in Lake County, California, which I visited in the year 1866. At that time the deposit was worked exclusively for sulphur, but it has since been successfully opened as a quicksilver mine. Believing that additional light on so interesting a subject would be welcomed by the scientific world, Messrs. Le Conte and Rising, of the University of California, made repeated visits to this mine during the years 1877, 1878, 1879, 1880 and 1881, and have published the results of their observations, made down to a considerable depth below the volcanic capping, to which my examination was necessarily confined.[1]

[1] Joseph La Conte, and W. B. Rising, "The Phenomena of Metalliferous Vein-formation now in progress at Sulphur Bank, California," *American Journal of Science*, xxiv. 1882, p. 23.

At the time of their earlier visits, namely from 1877 to 1880, the underlying country rock could be reached and examined in only one excavation, known as the "Waggon-Spring Cut," but in the summer of 1881 they had an opportunity of examining the stratified rocks underlying the lava to a depth of 260 feet. Since their previous visit a shaft had also been sunk some distance to the south of the Waggon-Spring Cut, about 150 feet outside the limits of the lava-flow, with the intention of reaching the ore body by means of drifts, the uppermost of which had been driven for a distance of 150 feet. Mr. W. Jackson, of San Francisco, who examined the volcanic rock, determined it to be an augite-andesite. The stratified rocks in its vicinity, where not concealed from view by a capping of lava, consist of sandstones and shales inclined at very high angles.

The phenomena observed were as follows:—For seventy or eighty feet from the shaft the rock is barren sandstone and shale, dipping to the south, and comparatively dry and cool. Then it becomes brecciated and highly charged with ascending hot water containing a large amount of alkaline sulphides, with excess of CO_2 and H_2S. In the hottest places the temperature of the water is 160° Fahr., and CO_2 bubbles up so profusely that a lighted candle near its surface is quickly extinguished. The heat of the freshly cut rock is often too great to be borne by the naked hand, and in this hot shattered rock the ore is found. The mine is worked with difficulty on account of the almost insupportable heat, but this has now been, to a great extent, removed by the more complete ventilation recently introduced. The lower drift had not at the time of their visit yet reached the ore body.[1]

The brecciated layer which forms the water-way is here, as in the Waggon-Spring Cut, composed of fragments of sandstone and shale, usually angular, but sometimes sub-angular, as if the edges had been either worn or dissolved away. In some places, where the ascending water is abundant, there is hot mud only between the fragments, but in others, where the rock is drier, and the solfataric action is exhausted, the fragments are firmly cemented by a paste

[1] In 1882 the work was progressing on five different horizons, namely:—104-foot, 157-foot, 210-foot, 260-foot, and 310-foot levels. The third, 210-foot level, had been pushed 232 feet, cutting through the ore body, and reaching barren rock on the other side. The fourth level had been pushed 136 feet, and had reached the ore body. The varying dips at these levels show that the strata are very much broken up.

of consolidated mud containing disseminated metallic sulphides, or wholly by deposits from solfataric waters. The vein thus becomes a mere breccia united by a paste of cinnabar, pyrites and silica, but chiefly by cinnabar. The spaces are sometimes entirely, and sometimes only partially, filled with the deposit, occasionally leaving hollows between the fragments. In this case the mass may have the appearance of an aggregation of pellets of cinnabar, but on breaking them they are found to have an angular fragment of rock as a nucleus. The deposit lining or filling the cavities is most commonly cinnabar, but sometimes consists of iron pyrites, or silica, or of all three arranged in alternate layers. The silica was found in all stages of consolidation; sometimes chalcedonic, sometimes cheesy, and sometimes gelatinous. The vein or deposit is largely enclosed in the brecciated stratum described, but is apparently not wholly confined to it. It is extremely irregular, sometimes widening out to many yards in extent, and then thinning down to a few inches, or even pinching out and disappearing entirely to again appear in a different stratum. Sometimes it is repeated, with barren rock between, whilst at others it leaves the brecciated layer and appears in the shattered sandstone either on one side or on the other. This deposit is in some places exceedingly rich, constituting a breccia united by a paste consisting entirely of cinnabar, which often constitutes more than one-half the weight of the entire mass. No free sulphur was found either here or at any depth beyond a few yards below the surface. Becker [1] has studied these deposits very carefully; his views on this subject have already been given on page 135. In 1894 this mine produced 348 flasks of quicksilver.[2]

From the commencement of operations in 1850 up to August 31st, 1863,[3] the new Almaden mines had produced 308,756 flasks of 76·5 lbs. each, or 23,619,834 lbs. of quicksilver from 51,157 tons of ore, equal to a yield of 23·09 per cent. From 1850 to the end of 1889 the production was 904,459 flasks, equal to 69,191,113·5 lbs. out of 631,395 tons, or 5·41 per cent. In 1870 the production was 14,423 flasks, and the yield of the ore 5·23 per cent., in 1880 these figures were respectively 23,465 and 2·93, in 1889 they were 13,100 and 1·73, and in 1894 the production was 7,235 flasks.

The New Idria Mine produced 7,600 flasks in 1873 and 1,005

[1] G. F. Becker, *United States Geological Survey*, xiii. 1888.

[2] *The Mineral Industry*, iii. 1894, p. 477.

[3] *The Eleventh Census of the United States*, 1890, p. 240.

in 1894. In the last-named year the chief producers next to the New Almaden were:—[1]

	Flasks.
Great Western	5,341
Napa Consolidated	4,930
Mirabel	4,229
Aetna	3,575

The following table shows the quicksilver production of California at intervals of ten years from 1850 to 1890, also for the years 1894 and 1895:—[2]

Year.		Flasks.
1850	Production	7,723
1860	,, ...	10,000
1870	,, ...	30,077
1880	,, ...	59,926
1890	,, ...	22,926
1894	,, ...	30,440
1895	,, ...	36,104

The total production from 1850 to 1889 is given as 1,544,844 flasks, worth $69,258,000.

Lead.

Lead ores occur in the Atlantic States,[3] in true veins, enclosed in the Azoic slates of New York, &c., in the form of argentiferous galena, associated with blende, iron pyrites and copper pyrites; in veins running parallel to the formation, especially in New England; and as irregular deposits in the unaltered Lower Silurian rocks of the State of New York and elsewhere. They are not, however, extensively worked, and exhibit no peculiarities of especial interest. A good deal of lead mining was carried on about 1870 in the neighbourhood of Phœnixville, Pennsylvania; the mines were remarkable chiefly for the very beautiful crystals of anglesite, wulfenite, cerussite and pyromorphite, which they yielded; it is also noteworthy that fluor spar occurred in the gangue. The most important lead regions of the United States are those of the Upper Mississippi Valley and Missouri.

[1] *The Mineral Industry*, iii. 1894, p. 477.

[2] *The Eleventh Census*, p. 187, and *California State Mining Bureau Bulletins*, Nos. 7 and 8.

[3] J. D. Whitney, *The Metallic Wealth of the United States*, p. 382; *ibid.* "Report on the Upper Mississippi Lead Region," *Geol. Survey of Wisconsin*, i. 1852.

Lead ore was first discovered in the south-west by Le Sueur, who made a voyage up the Mississippi in 1700. The first mining appears to have been undertaken in 1788 by Dubuque, a half-breed Indian trader, and was carried on by him until his death in 1809; but it was not until 1827 that lead miners began to spread themselves over the Wisconsin lead region, from which time the quantity of lead produced rapidly increased until 1845; after which period, however, it again declined.

The Upper Mississippi lead district is included within the boundaries of three States, namely, Wisconsin, Illinois, and Iowa, but about five-sixths of the lead-producing area belong to Wisconsin. The deposits of lead ore are developed in the Galena or Upper Magnesian Limestone of the Trenton period of the Lower Silurian formation, and extend over an area of some 140 geographical square miles. There are no deposits of lead in the valley of the Mississippi which can be considered as coming in any way under the head of true veins, as they are invariably limited in depth, and are enclosed in a geological formation of which the productive portion does not generally exceed a hundred feet in thickness.[1] Whitney distinguishes various forms of these deposits:—The simplest variety is the *sheet*, the characteristic mode of occurrence of lead ores in the Mississippi valley, which is a solid mass of ore filling a vertical fissure; the ore remaining as it was first deposited, and the rock exhibiting no evidence of having undergone decomposition. The dimensions of such sheets are very variable, but generally the thickness does not exceed three inches, whilst their longitudinal extension is not great, usually varying from a few yards to a hundred. From twenty to forty feet may be considered the most usual limit in vertical extension; but in some instances a much greater depth has been attained whilst following down an unbroken mass of ore. In sheet deposits there are rarely any of the ordinary accompaniments of a true vein, such as gangue or veinstone, and the walls are never smooth or striated. Should the ore give out, the crevice becomes filled with clay, ochre, or calc spar, whilst quartz is never present.

An *opening* is the widening out of a crevice in strata in which the conditions are favourable to the accumulation of lead ore, and is filled with galena surrounded by ferruginous clay. When the dimensions are very irregular, the fissure contracting and expanding suddenly and frequently, so as to give rise to numerous isolated cavities of different sizes connected by the general line of fissure,

[1] See, however, p. 167.

the whole is called a *crevice with pocket openings.* The *cave opening* is a magnified form of the pocket opening. An expansion of this kind in Levin's Lode, near Dubuque, was 130 feet long, 45 feet high, and 30 feet wide. There are frequently great irregularities in the vertical height of such openings, which sometimes rise into conical cavities, called chimneys, often lined with stalactites of calc spar and galena. *Crevice openings* are chiefly confined to the upper portion of the Galena limestone, whilst in the lower portions of that rock *flat sheets* and *flat openings* occur as characteristic forms of deposit. The difference between vertical and flat sheets is one of position only. Flat sheets are made up of blende, calamine and pyrites, associated with galena. Calcite and heavy spar are found, in some cases, as vein-stuff, whilst quartz is wholly wanting. In flat sheets the minerals are sometimes arranged symmetrically. The most recent researches upon these lead deposits of the Mississippi valley, which are characteristic deposits in limestone, have already been referred to on page 166.

The principal ore in these deposits is a very pure galena, poor in silver (0·001 to 0·002 per cent.), crystallising, principally, in cubes. It is frequently accompanied by blende and zinc carbonate, the latter being called *dry bone* by the miners, on account of its cellular, bone-like structure. Iron and copper pyrites are comparatively rare, but brown iron ore seems to constantly occur with the lead and zinc ores. Calcite and heavy spar are subordinate, whilst quartz and the compounds of lead with arsenic and phosphorus are entirely absent.

The occurrence of mammoth and other bones in crevices with the lead ore, as well as in the clay and sand near the surface, has been repeatedly noticed by those who have been engaged in investigating the geology of the lead region. Casts of fossils in sulphide of lead are not unfrequent in this region, a fact which is alone sufficient to demonstrate the aqueous origin of the ore.

The first mining operations in Missouri were commenced in 1720, the celebrated La Motte Mine being one of the most important opened at that period. The principal deposits are situated in Washington County, but there are some others in the counties of Franklin and Jefferson. The geological position of the metalliferous deposits of Missouri is very similar to that of the Mississippi lead mines.

Practically the whole of the lead produced in the Western States of America is argentiferous and is obtained more for the sake of the silver than of the lead; the falling off in the silver production of the United States in recent years has accordingly entailed a corresponding diminution in the output of lead. Exact statistics are hardly to be obtained, especially because so few mines are worked for lead alone, silver or zinc being generally associated with the former metal, whilst a good deal of lead is also extracted in the United States from imported ores, these coming chiefly from Mexico and from the Kootenay district of British Columbia.

The total annual production of lead in the United States during the year 1882 was 132,890 tons, of which more than one-half was produced in the western States and Territories. In the year 1882, Colorado produced 58,642 tons of metallic lead, and Utah 30,000 tons of that metal.

In 1889[1] the Rocky Mountain States and Territories produced 130,903 tons of lead ore, valued at $4,712,757, the chief producers being Colorado with 70,788 tons, worth $2,101,014, and Idaho with 23,172 tons, worth $1,042,629. The production east of the Rocky Mountains was 50,238 tons, valued at $1,754,380, by far the most important contributor being Missouri, with 44,482 tons, worth $1,571,161. The total production of lead ore was 181,141 tons, and the production of metallic lead from native ores is estimated at somewhere about 127,500 tons. The total production of lead from home and foreign ores in this year was 153,709 tons. The following table[2] shows the production of lead from American ores between 1890 and 1894, including an annual amount of about 5,000 tons of hard antimonial lead :—

Year.	Tons.
1890	142,065
1891	176,651
1892	182,677
1893	166,678
1894	160,867

Zinc.

Ores of zinc[3] are widely distributed over the United States of America, the deposits of that metal in New Jersey exhibiting some features of especial interest. At the Eaton Mine, in New

[1] *Eleventh Census of the United States*, 1890, p. 163.

[2] *The Mineral Industry*, 1894, p. 403.

[3] J. D. Whitney, *Metallic Wealth of the United States*, p. 347 ; R. W. Raymond, "Zinc Deposits of Southern Missouri," *Trans. Amer. Inst. Min. Eng.*, viii. 1880, p. 165.

Hampshire, there is a vein six feet in width, traversing altered Palæozoic rocks, which consists chiefly of yellow blende, enclosing masses of argentiferous galena. Ore of a similar character is found at the Shelburne Mine, and at various other localities in the same State. At Warren there is a thick bed of black blende, associated with galena and iron pyrites. In the State of New York zinc ores have been obtained from mines in the vicinity of Wurtsboro', in Sullivan County, where they occur in a bed parallel with the stratification of the Shawangunk Mountain. According to Professor Mather, it forms a mass, varying from two to five feet in thickness, the larger portion of which consists of a siliceous rock, similar to that forming the roof and floor, containing fragments of greenish and blackish slates. The metalliferous constituents are blende, galena, copper pyrites and iron pyrites, associated with crystallised quartz. The leader of solid ore varies in thickness from a mere trace to three feet.

The zinc deposits of New Jersey are situated in Sussex County, on a range of hills, which, commencing near Sparta, extends in a southerly direction through Stirling to Franklin, where the deposits are worked. They occur in association with a white crystalline limestone, which can be traced from Orange County in the State of New York to beyond Stirling, and is probably of Lower Silurian age. An intrusive felspathic rock appears to form dykes in this limestone, which is tilted at a considerable angle. At Stirling Hill a bed of zinc ore rests with a steep south-easterly dip against a bed of franklinite, both exactly coinciding in dip with the bed of limestone in which they are enclosed. The ore consists of the red oxide containing 80·26 per cent. of zinc, and 19·74 per cent. of oxygen, and is found only in the State of New Jersey. The bed of franklinite on which the zinc ore rests varies from twenty to thirty feet in thickness. At Mine Hill, Franklin, the same succession of limestone and metalliferous beds is to be observed, but the intrusive rock is there said to be syenite, the blue limestone having been converted into a white crystalline mass along the line of contact of the two rocks, and in this both the zinc ore and the franklinite are intercalated in the form of beds. The mode of formation of these deposits presents problems of great difficulty, nothing like them being known anywhere else. The limestone associated with them is manganiferous and the manganese of the franklinite may have been derived from this source. The guess may be hazarded that these deposits were originally deposits of calamine in limestone, such as are known elsewhere. The limestone contained some carbonate of manganese, and when it underwent metamorphism, a series of metamorphic changes were also brought about in the mineral deposits, as a result of which the minerals zincite, willemite, franklinite, &c., were produced.

Amongst the numerous deposits of zinc ore in the State of Pennsylvania those of the Saucon Valley, near Friedensville, are the most important. The ore there consists almost entirely of silicate of zinc, and is remarkably free from any admixture either of lead or iron. The deposits are in the form of included beds in a compact blue limestone of Silurian age, apparently the equivalent of the Calciferous Sandstone of American geologists.

Lead mining in Missouri appears to have been considerably affected by competition with the mines of the western States and Territories; but simultaneously with this depression the development of new zinc deposits has caused a revival in this branch of industry. The zinc-bearing region in south-western Missouri is very extensive, the ores being chiefly carbonate and hydrous silicate of zinc. The deposits in the north and south-east of the State are said to be in Silurian rocks, but those of the south-west are Sub-Carboniferous. This difference in age of the enclosing rocks does not, however, necessarily prove a similar difference in the age of the deposits. The Sub-Carboniferous limestone of the south-west is nearly horizontal, is characterised by numerous flinty segregations, and is occasionally shaly. In this formation occur the ore deposits, which are irregular in shape and distribution, although but little is known of their extent. They appear, however, to be limited in height, width and length, and to abut in all directions against barren rock. Iron pyrites is plentiful in a few mines only, and in some of them the ore consists of a porous skeleton of silica, the pores of which are filled with blende. From this to solid flint rock, with disseminated specks of blende, all forms of transition are observed. The mineral district[1] covers an area of about a hundred miles from east to west by thirty from north to south, extending into both southern Missouri and Kansas. Zinc was first discovered here in 1870–71, and regular mining began about 1873. From that time to the end of 1894 the total production was 1,407,832 tons of ore, valued at $27,722,858. In 1894 the output was 142,642 tons of ore, worth $2,337,543.

The production of metallic zinc in the United States

[1] J. R. Holibaugh, *Lead and Zinc Mining in Missouri and Kansas*, 1895.

during the year 1882 is estimated at 33,765 tons. During the eleventh census year, 1889,[1] the output of ore was as follows :—

Production of Zinc Ore in the United States during 1889.

State.	Weight.	Value.
	Tons.	$
Arkansas	130	3,250
Iowa	450	3,600
Kansas.	39,575	299,192
Missouri	93,131	2,024,057
New Jersey and Pennsylvania	63,339	175,052
New Mexico	140	2,520
Southern States.	12,906	141,560
Wisconsin	24,832	400,568
Total	234,503	3,049,799

During this year there were treated 196,309 tons of ore, with a production of 58,860 tons of spelter and 16,970 tons of oxide of zinc. In 1884 there were produced 38,544 tons of spelter, and 74,004 tons in 1894.

Tin.

The occurrence of tin ore in the United States is so rare that the search for it has almost been given up as hopeless, some authorities going so far as to say that it would never be found in paying quantities. Tin ore was, however, discovered in Alabama under conditions that at one time looked promising, and a Mr. Gesner put up machinery two miles south-east of Ashland, Clay County, Alabama, in order to mine the tin ores found there. The property embraced nearly a square mile, and Mr. Gesner had forty-five stamps working about 1880 ; the results, however, were unsatisfactory, and the enterprise had to be abandoned.

At Winslow, in the State of Maine,[2] veins of cassiterite traverse an impure, gray, micaceous limestone, which is found in many parts of this region, and is subordinate to the gneissic series. The veins, which are seldom more than an inch or two in thickness, are abundant through a considerable extent of the rock, and are interlaminated with it, occupying spaces between the sedimentary layers, which are distinctly marked by different shades of colour;

[1] *Op. cit.* p. 168.

[2] T. Sterry Hunt, *Trans. Amer. Inst. Min. Eng*, i. 1873, p. 373.

occasionally, however, they for a short distance cut across the stratification. The veinstone is purple fluor spar, white mica and quartz. In this gangue the cassiterite is disseminated in small crystalline masses, sometimes half an inch in diameter, together with a little mispickel. Dana mentions scanty occurrences of cassiterite at Paris and Hebron in Maine, and at Chesterfield and Goshen in Massachusetts. But none of these deposits have hitherto proved commercially valuable. There is an occurrence of tin oxide in Missouri which seems to be a replacement of titanic oxide in sphene, but which can only be regarded as a mineralogical curiosity. Tin ore occurs in the Brewer Mine, Chesterfield County, South Carolina (*see* page 786), but apparently not in workable quantities, and a small deposit has been opened up in Virginia, out of which 1,000 tons of tin-bearing rock are officially stated to have been raised in the eleventh census year, but the percentage of metal is not stated, nor does it appear that any metal was ever smelted from it.

Discoveries of stream tin have been made in Idaho, but no washings have yet been undertaken. Small pebbles of tin ore have also been found in Prickly Pear Creek, Montana. There is likewise a deposit of tin ore in the shape of small veins carrying quartz, chlorite, oxide of iron and cassiterite, in the granite of the Temescal Range, San Bernardino County, California. Some rich specimens have been obtained from this locality, and during the winter of 1860–61 a great number of claims were taken up. In 1890 and 1891 a great deal of work was done in this district, and it is reported that up to May, 1891, twelve tons of metallic tin had been produced. Even if this be true, it does not seem that any more has been obtained, and there is now nothing doing on these deposits.

Tin ore certainly occurs over a very wide area in South Dakota,[1] and an attempt was made to work it on a very large scale by a powerful company, the Harney Peak Tin Mining Company, Limited, which was formed about 1888. Tin ore was first discovered in the Black Hills of Dakota by R. H. Pierce in 1877. The formation here consists of mica schists and slates, containing masses of granite, lenticular and parallel to the direction of the bedding. Most geologists regard these as intrusive granites, though F. B. Carpenter[2] thinks that they are veins. The granite

[1] *Eleventh Census of the United States*, 1890, p. 251.

[2] "Ore Deposits of the Black Hills of Dakota," *Trans. Amer. Inst. Min. Eng.* xvii. 1889, p. 570.

is coarsely crystalline, crystals of felspar and mica many inches in diameter being common. The cassiterite also occurs at times in large crystals, and sometimes finely disseminated; spodumene, apatite, columbite, and tantalite also occur in these deposits, together with a number of other minerals such as generally accompany cassiterite; neither fluor spar nor topaz seems, however, to occur here. It is said that in the eleventh census year 22,000 tons of tin-bearing rock were mined; there does not, however, appear to be any record of its having produced any tin. In 1885 it is said that a trial run of 400 tons produced seven tons of metallic tin, and about 1888 a bulk sample of 40 tons was sent to England, which yielded at the rate of 2·6 per cent. of metal. The company appears now (1896) to be in process of liquidation.

There are no records of tin ever having been produced with profit in the United States, if indeed any tin has ever been smelted at all in the Union.

Antimony.

Antimony occurs in the north-western portion of Sonora, where a short range of mountains, the Sierra del Alamo Muerto, skirts the eastern shore of the Gulf of California at about thirty miles from the sea, and fifty from El Altar. On the northern flank of this range, an area of considerable extent is strewn with quartz and a heavy yellow mineral. The latter is said to have been long ago amalgamated for silver, but to have yielded so base an amalgam as to have been rejected as an ore of silver. Its true character appears to have been overlooked for some time until samples were sent to England, and the value of the mineral as a pure oxide of antimony was at once recognised. Shortly afterwards arrangements were made with the owners to ship the ore for treatment to works erected at Oakland, California. There would appear to be three systems of veins within an area of about four square miles. The most northerly group, the San José, was in 1881 the most productive in antimony, but it carried no silver. The Santa Margarita group lies between the preceding and the Argentine group. Both the second and third groups are argentiferous, but the first, although containing no silver, was, when opened, richer in antimony than the two latter. The size and yield of the veins have proved very variable, but the area over which the mineral is found is so large, and the number of veins so great, that the district promises to be of some importance, though to what extent more extended mining alone can determine.[1]

In 1895 [2] California produced 33 tons of antimony, valued at $1,485.

Ores of antimony likewise occur in the Coyote mining district, Utah Territory, where stibnite occurs in large quantities in the form of horizontal beds or layers, in a soft sandstone, which rises in precipitous bluffs on each side of the valley of Coyote Creek. This sandstone is underlain by a thin bed of limestone, and by a conglomerate of much worn and rounded quartz boulders, forming the base of the bluffs. The antimony occurs just above the junction of the sandstone with the limestone, and in some places has been found in the conglomerate; generally, however, the layers of antimony ore are enclosed in the sandstone. The thickness of these layers varies at different points from a few inches to about thirty inches. It may in some cases be thicker than this, and there are evidences of two more beds, one above another. The workings never progressed sufficiently to show the full extent of the beds as regards their thickness and number,[3] for soon after 1881 these mines were abandoned as not profitable under the then existing conditions.

Sulphide of antimony was discovered in South-western Arkansas in 1873, and since that date three mines have been opened, from which a number of antimonial minerals have been obtained. The most extensive deposit is the Stewart Lode, which was discovered in 1877, and courses N. 13 E., with a nearly vertical dip. This would appear to be one of the few localities in the United States where ores of antimony are found in workable quantities.[4]

Arkansas produced 65 tons of ore, yielding 25 tons of star regulus, valued at $10,000, in 1889. The State of Nevada was the largest producer in that year, its output being 200 tons of ore, yielding 90 tons of regulus, worth $18,000; the chief mines are at Bernice. Mines are also worked at Kingston, in Idaho, and in Montana. All these deposits are irregular in character, and there is very little regular mining for antimony carried on in the United States.

[1] J. Douglas, Jun., *Engineering and Mining Journal*, March 4th, 1882.

[2] *California State Mining Bureau*, Bulletin No. 8, 1896.

[3] W. Blake, *Report upon the Antimony Deposits of Southern Utah*, New Haven, 1881.

[4] C. P. Williams, "Antimony in Arkansas," *Trans. Amer. Inst. Min. Eng.* iii. 1875, p. 150; C. E. Wait, *ibid.* viii. 1880, p. 42.

The following table shows the weight and value of star regulus produced in the Union from the years 1884 to 1894 :—[1]

Year.	Weight.	Value.
1884	60 tons	$12,000
1885	50 „	10,000
1886	35 „	7,000
1887	75 „	15,000
1888	100 „	20,000
1889	115 „	28,000
1890	129 „	40,756
1891	278 „	47,007
1892	200 „	36,000
1893	350 „	63,000
1894	220 „	39,000

Copper.

The Lake Superior region[2] during the year ending June 1st, 1880, furnished 90·48 per cent. of the total amount of copper produced in the United States east of the 100th Meridian, but exclusive of the yield of the western States and Territories, California, Colorado, Idaho, Arizona, &c. Since that date copper mining in the States has completely changed its conditions, and has developed with extraordinary rapidity, Montana having come to the front with an output even greater than that of Michigan (the Lake Superior region), the latter having remained more nearly stationary. Arizona has also become a large producer, until in 1894 the Lake Superior region was producing only 32 per cent. of the total output.

This is nevertheless one of the most interesting copper districts in the world, the metal occurring in masses of very various sizes in bedded trappean rocks associated with interstratified sandstones and conglomerates. The copper is found almost wholly in the native state, and occurs not only in veins but also disseminated in amygdaloidal and conglomerate rocks, on which some of the richest and most productive mines are worked. The Lake Superior copper belt extends from Keweenaw Point south-west to Wisconsin, and thence across the State to Minnesota. Its

[1] *Eleventh Census of the United States*, 1890, p. 337; *The Mineral Industry*, 1894, p. 72.

[2] J. D. Whitney, "Metallic Wealth of the United States"; Raphael Pumpelly, "Copper-bearing Rocks," *Geol. Survey of Michigan*, i. 1873.

length is about 130 miles and its width six, occupying portions of the counties of Keweenaw, Houghton, Isle Royale and Ontonagon. Beginning at the north-east, many mines have been opened from Keweenaw Point to the south-west, including the celebrated Calumet and Hecla Mine in Houghton County. There are various mines in Ontonagon County, and others on Isle Royale in Lake Superior.

Keweenaw Point is composed of two distinct formations; on the eastern side are sandstones, whilst on the western is an enormous development of alternating trappean rocks and conglomerates. The relative age of these formations has given rise to much discussion. Both have been referred to the Potsdam epoch by Foster and Whitney, and by Sir W. Logan to the Chazy; whilst Mr. Bell, of the Canadian Survey, considers the cupriferous rocks to be of Triassic age, thus agreeing with Jackson and Owen in a view afterwards abandoned by the latter. Pumpelly is of opinion that the cupriferous series was formed before the tilting of the Huronian beds, upon which it rests conformably; and that, after the elevation of these rocks, sandstone and shales containing fossils, which show them to belong to the Lower Silurian period, were deposited as products of the erosion of the older rocks. It is, however, still uncertain whether they should be referred to the Potsdam, Calciferous, Quebec, or Chazy epoch; Wadsworth[1] has more recently made them out to be of Lower Cambrian age.

According to H. Credner,[2] copper occurs in this region in four different forms of deposit, namely:—

1st. In true fissure veins which traverse the melaphyres and amygdaloids and are only productive in those rocks, but become contracted and pinched when they enter the diorites, and are totally unproductive as soon as they pass into the conglomerates or sandstones. In such lodes masses of native copper, each weighing many tons, are found associated with native silver, quartz, calcite, laumonite, prehnite, apophyllite, natrolite, desmine, fluor spar, epidote, and chlorite.

2nd. As entirely or partially filling vesicles in amygdaloidal melaphyres, as is the case not only in the vicinity of the lodes but also at considerable distances from them. At the Copper Falls Mines the amygdules are often entirely filled with native copper, but, when their filling is not exclusively metallic, the copper is

[1] *Geological Survey of Michigan*, 1893, p. 85.
[2] *Neues Jahrb. für Mineral.* 1869, p. 1.

accompanied by native silver, calcite, quartz, chlorite, laumonite, prehnite, analcime, epidote, datolite, iron glance, &c.

3rd. As an accessory constituent of an epidote rock lying in irregular layers between the various sheets of melaphyres.

4th. As the cementing material, or an accessory portion of the cementing material, of a breccia occurring between the sheets of melaphyre. The Calumet and Hecla deposit is an example of such a metalliferous breccia.

An account of the results of the most recent investigations respecting the deposits of this region has already been given, page 185.

Crystals of silver, free from copper, are not unfrequently found deposited on copper containing no silver, and the masses of native metal usually exhibit, with electrotype fidelity, an exact cast of the surfaces of the enclosing rocks.

When, as sometimes occurs, a mass of copper is met with extending some twenty or thirty feet along the course of a vein, and weighing considerably above a hundred tons, its removal is attended by a certain amount of difficulty. In order to extract such a deposit of "mass copper," the rock is first stoped from one side of it, and the metal subsequently divided, by means of cross-cut chisels, into fragments of such dimensions as to admit of being taken upon rollers to the shaft and thence raised to the surface.

The name of "barrel work" is applied to the smaller pieces of copper, each usually weighing a few pounds only, which are too large to go to the stamp mills, and are consequently picked out to be sent away in barrels. In the more productive mines, considerable quantities of this lump copper are obtained during the breaking and preparation of the "stamp work." It usually contains from 60 to 70 per cent. of copper. The largest proportion of the cupriferous material, in all the mines of Lake Superior, consists, however, of stamp work, which requires to be broken into pieces of moderate size before being subjected to the operations of stamping and washing, thus producing so-called "mineral" with about 80 per cent. of metal.

The production of the Lake Superior mines during the year 1882 amounted to 28,491 tons of copper, of which amount 16,027 tons were supplied by the Calumet and Hecla Mine alone. In 1889 the total amount of ore raised in this district was 2,433,733 tons, producing 43,728 tons of copper, being at the rate of 1·8 per cent.; some of the mines, however, are working on a produce of less than 1 per cent. of metal. The average in 1893 was 2·9 per cent. The output of these mines has been increasing steadily, until in 1894 it reached 57,263 tons of copper, out of which total the Calumet and Hecla Mine produced more than one-half, or 30,921 tons. Next to this mine rank the Quincy and the Tamarack, each with about 7,700 tons of copper. The shafts at these Lake Superior mines are amongst the deepest in the world; two at the Tamarack Mine are over 4,000 feet deep, and one in the Calumet and Hecla has passed that depth, and is to be continued to a total depth of 5,000 feet.

The great copper deposits near Butte City, Montana, were not opened up until the year 1881, when railways first traversed this region; in 1883 large masses of copper ore were struck in the Anaconda Mine, and by 1888 the produce of this mine even exceeded that of the Calumet and Hecla.[1] A number of important mining companies are working a lode, or, more properly, a mineral belt, that has been traced for over three miles in length, running approximately east and west. The country rock is granite, traversed by dykes of rhyolite,[2] whose general trend is north and south, and which seem to have broken through the granite; the latter is also traversed by dykes of quartz porphyry. The direction of the ore belt follows the general direction of the fissure planes, along which the ore was deposited, there being often several such, approximately parallel to each other, but uniting in places, running out and coming in again. Emmons (*loc. cit.*) concludes that the granite was fissured and shattered along this line by some dynamic movement that may, perhaps, be referred to the rhyolite eruption; mineralising solutions penetrated through the rock thus shattered, and decomposed the granite, forming the ores by metasomatic interchange. Some of the ore occurs in thin reticulated strings, like a stockwork, some impregnating the decomposed granite, and some in extensive ore masses; one in the Anaconda Mine is 150 feet wide. It has already been noted that most of these ores at the outcrop carried silver, mainly as chloride, and practically no copper up to a depth of 400 feet, at which level a belt of very rich oxysulphides and other secondary ores, running up to fifty per cent. of copper in places, was passed through, till the normal ores of the deposit were reached.

The ores in depth are chiefly bornite, copper glance, and

[1] James Douglas, "The Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.* xix. 1890, p. 678.

[2] S. F. Emmons, "Notes on the Geology of Butte, Montana," *Trans. Amer. Inst. Min. Eng.* xvi. 1887, p. 49.

other sulphides, carrying silver in proportions of between ½ oz. to 2 oz. to the ton per unit of copper. The ores vary from 6 to 10 per cent. of copper, but the yield will no doubt be somewhat lower in depth.

Of recent years the Anaconda Mine has produced just about one-half of the total copper output of the State of Montana, and the Boston and Montana and the Butte and Boston properties together about one-third, the remaining sixth being contributed by various smaller mines. In 1889 Montana produced 48,934 tons of copper from 698,837 tons of ore. The following table[1] shows the production of copper in Montana since 1889 :—

	Tons.
1890	55,478
1891	56,180
1892	80,525
1893	77,150
1894	91,547

In Arizona[2] there are three main productive centres, Clifton, where the Arizona Copper Company is the chief producer, Bisbee, where the important mines of the Copper Queen are situated, and Globe, where the Old Dominion is the leading mine. In all these districts the ore occurs in essentially similar forms ; it occurs either in Carboniferous limestone, or at the contact of that rock with sandstone or with granite, porphyry, or other eruptive rocks. Although, in some of the latter cases, the copper ores seem to have to some extent replaced the granite, sandstone, or other rocks, as the case may be, yet the genesis of the deposits is referable to the limestone, its solubility being the cause that enabled the copper-bearing solutions to penetrate the rocks and produce the deposits. The ores are principally carbonate and oxide of copper, associated with oxide of iron, the decomposition products probably of copper pyrites. Masses of sulphide ore are found occasionally, and there seems little doubt that in depth the oxidised ores will be completely replaced by sulphides, as they have already been partially. The great depth to which the decomposition of the ore has extended is no doubt referable to the chemical action of the calcareous country rock.

In 1889 there were raised in Arizona 145,586 tons of ore, which

[1] *The Mineral Industry*, iii. 1894, p. 161.

[2] James Douglas, *loc. cit.*

yielded 15,681 tons of copper. The following table [1] shows the production of copper since 1889:—

	Tons.
1890	18,489
1891	20,947
1892	19,192
1893	21,887
1894	22,266

The chief producers in the last-named year were:—

	Tons.	
Copper Queen	6,484	metallic copper
United Verde	5,452	metallic copper
Arizona	4,968	metallic copper

In Texas [2] copper ores are known in the Permian formation in two rather extensive districts on Red River and on Brazos River, but although they have been repeatedly worked, favourable economic results have not yet been obtained. These ores occur in the lower strata of the Permian, and are by no means closely confined to one horizon; in many places they are developed at two distinct horizons.

The Permian measures consist here of soft sandstones, clays, marls and conglomerates. The copper ores appear chiefly in the marls and clay-rocks as cuprified branches of trees, sometimes several inches in diameter, and as nodules of copper ore, four to six inches in diameter, most or all of which are of fossil origin; it also occurs in smaller nodules and impregnating the marl or clay-rock. The ores are chiefly silicates and carbonates of very variable richness, in some cases up to 60 per cent. of metal. The occurrence is highly interesting from a geological point of view, though its economic importance seems to be doubtful.

Copper ores associated with quartz occur in true lodes in the State of Maine at Dexter, Lubec, Parsonsfield, and various other localities, but are of little practical importance.

According to the Census Bulletin, during the year ending June 1st, 1880, three mines in Hancock County, employing ninety-seven workmen, produced 12,500 tons of rough ore, equivalent to 41½ tons of metallic copper, worth $10,125.

[1] *The Mineral Industry*, iii. 1894, p. 159.

[2] E. J. Schmitz, "Copper Ores in the Permian of Texas," *Trans. Amer. Inst. Min. Eng.* February, 1896.

Several copper mines have been worked in the State of Maryland, particularly in the vicinity of Liberty and New London, in Frederick County. The ores, which principally consist of various sulphides, are enclosed for the most part in a mixture of talcose slate and limestone. At the Dolly Hide Mine, in this district, the workings are carried on upon a broad band of crystalline limestone, which, where best developed, is nearly 100 feet in thickness, and contains numerous parallel bands of ore mixed with a quartzose material coloured brown by the oxides of iron and manganese. The rock on each side of the belt of limestone is an argillaceous slate. At the Springfield Copper Mine in Carroll County, copper ore, chiefly in the form of copper pyrites, occurs in a vein running N. 25° E., with, for the first sixty feet, a dip south-east, and then becoming nearly perpendicular. This vein is at the surface from twenty to twenty-four feet in width, and was originally worked for iron ore. At Mineral Hill, near Sykesville, there are four veins enclosed in talcose and chloritic slates. In 1880 one mine in Carroll County employing six men produced eighty-two tons of copper ore.

The copper ores of Missouri, as well as the lead ores, are chiefly contained in Lower Silurian strata, which have been deposited in depressions of the Azoic rocks. Copper ore was first discovered in Ste. Genevieve County[1] in 1863 by a German farmer, who had occasion to make a road from his house into the neighbouring valley, and whilst so engaged noticed pieces of a green-coloured mineral, of which he collected specimens, which were subsequently forwarded to St. Louis for analysis.

The Ste. Genevieve copper deposit occurs in the second of the Magnesian Limestone Series of the Lower Silurian system, and in the immediate vicinity of the mines this rock attains a thickness of upwards of 250 feet. East of this the Carboniferous system is met with, and continues to the river above Ste. Genevieve, whilst below the town Quarternary deposits occupy the area included between Dodge Creek, Mill Creek, and the Mississippi River. So far as can at present be determined, the copper deposit consists of two nearly horizontal beds of ore between strata of chert enclosed in Silurian limestone. The uppermost of the two known cupriferous horizons, and that from which nearly the whole of the ore hitherto extracted from the Cornwall Mine has been obtained, is 250 feet above the bed of the stream traversing

[1] Frank Nicholson, "A Review of the Ste. Genevieve Copper Deposit," *Trans. Amer. Inst. Min. Eng.* x. 1882, p. 444.

the adjacent ravine. The lower level seam, that worked at the Swansea Mine, is at least 150 feet below the upper one. The principal ore is copper pyrites, which is found in a massive form, and varies in thickness from three inches to several feet. Fig. 121, after a sketch by Mr. Nicholson, taken in the Vallé drift of the Cornwall Mine, 250 feet from its mouth, shows the sequence and approximate thickness of the various strata in that locality. The ore is here compact copper pyrites almost free from gangue, but about fifteen feet from the point where this sketch was taken

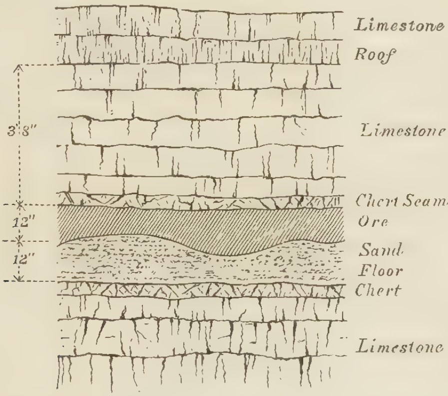


FIG. 121.—Ore deposit, Cornwall Mine; vertical section.

the ore seam is entirely lost, to again make its appearance at no very considerable distance.

During the tenth census year, three mines in the County of Ste. Genevieve, employing eighteen persons, produced 1,051 tons of copper ore, representing 115 tons of ingot copper, worth $25,730.

The most important copper mine worked in North Carolina is the Ore Knob.[1] This mine is situated not far from the New River in Ashe County, North Carolina, and is on a true vein which cuts the strata of gneiss and mica schist of the region. These rocks dip 45 S.E., whilst the lode is vertical with a course N. 60° E. Both country rock and lode are decomposed down to considerable depths, the latter exhibiting a strong capping of gossan. At a certain depth the lode becomes charged with carbonate and red oxide of copper, which still lower down are replaced by rich sulphuretted ores of that metal. This deposit was worked irregularly before the Civil War,

[1] T. Sterry Hunt, "The Ore Knob Copper Mine," *Trans. Amer. Inst. Min. Eng.* ii. 1874, p. 123.

and was again opened in 1873. The outcrop has been traced for a distance of 1,900 feet, and copper ores have been met with in five different shafts within a distance of 661 feet. A drift has, moreover, been carried for the above distance through solid ore. The breadth of the lode varies from six to fourteen feet and the outcrop of gossan is, in some parts, twenty feet in width. In 1874 the Ore Knob yielded a net profit of $60,302. Copper Knob, situated in the Blue Ridge, near the Ashe-Wautauga railway, is worked on a vein, or rather group of veins, of which the most important carries, in addition to quartz, erubescite, yellow copper ore, malachite, chrysocolla, specular iron ore and pyrites, with occasionally free gold and silver. Two mines, both situated in Ashe County, giving employment to 328 persons, produced, during the year 1879-1880, 24,680 tons of ore, representing 820 tons of metallic copper, value $350,000.

In Montgomery and Chester Counties, Pennsylvania, cupriferous veins occur at or near the junction of the gneiss and Triassic Sandstone. This metalliferous zone extends in a general east and west direction across the Schuylkill River, occupying a range of country some six or seven miles in extent. Within this space there are ten or twelve lodes, some of which are said to be confined to one formation and some to the other; whilst others again traverse both. Professor Rogers states, as a general fact, that those veins which are confined chiefly or entirely to the gneiss bear lead ore as their most abundant mineral, whilst those which are restricted to the red shale usually contain more copper than lead.

During the tenth census year one mine in Montgomery County, employing ten hands, produced 289 tons of ore, representing 20 tons of ingot copper, value $5,630.

Numerous deposits of copper ore are enclosed in the Huronian rocks of South-western Virginia, East Tennessee, and Georgia. This belt, which extends over a length of nearly sixty miles, has been worked, to some extent, at three different points, namely:—Carroll County in Virginia; Ducktown in Tennessee, and Canton in Georgia. Of these deposits that of Ducktown has been the most extensively worked, and is consequently known to a greater depth and over a larger extent than either of the other two.

The cupriferous deposits of Tennessee[1] are situated in the

[1] J. D. Whitney, *Metallic Wealth of the United States*, p. 322; H. Credner, *Berg. und Hüttenm. Zeit.* 1867, p. 8; 1871, p. 370.

immediate vicinity of the Ocoee River, in the extreme south-eastern corner of the State. The ores are contained in micaceous schists, which dip at a high angle to the south-east, have a strike of N. 20° E., and enclose lenticular ore masses which may be followed, with but comparatively few interruptions, for a distance of five miles. These, which sometimes attain a very considerable length, with a thickness occasionally exceeding fifty feet, are at Ducktown arranged in three parallel zones separated from one another by bands of unproductive rock. According to Whitney and Credner, the metalliferous deposits of Ducktown are not only parallel to one another but also to the strike and dip of the enclosing rocks, and consequently in this respect resemble the great pyritic masses of Schmöllnitz, Rio Tinto, &c. Throughout the whole extent

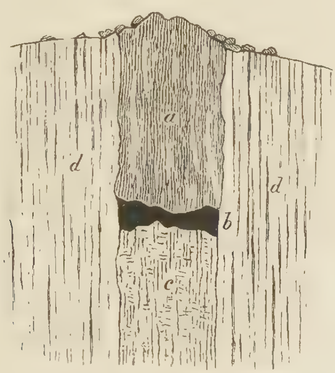


FIG. 122.—Section of deposit, Ducktown.

of their course these deposits exhibit a remarkable uniformity in their formation. The outcrop is usually rendered conspicuous by a heavy gossan, by which the surface of the ground is often covered with masses of ferruginous material over considerable areas. On sinking to a sufficient depth through this gossan, *a*, the section represented in Fig. 122 is obtained. Beneath the ferruginous outcrop is found a horizontal layer of cupriferous ore, *b*, of variable thickness, and of a width corresponding to that of the vein. Immediately under the copper ore, and separated from it by a well-defined line, is the unaltered veinstone, *c*, consisting of an intimate mixture of common iron pyrites, magnetic pyrites, and a little yellow copper ore, associated with quartz and, occasionally, with actinolite. This undecomposed veinstone contains on an average about 1½ per cent. of copper, but richer patches of copper ore sometimes occur in the mass. The gossan, *a*, as well as the copper ore, *b*, mainly consisting of a mixture of the sulphides of iron and copper, often enclosing cubical crystals of iron pyrites, are evidently the result of the decomposition of the unaltered ore which once occupied their place. The sulphide of copper, forming a considerable proportion of the deposit, *b*, has obviously been derived from the ore now converted into gossan; and, when stopping at Ducktown during the summer of 1857, I (J. A. P.) not only remarked that some of the springs in the neighbourhood of the deposits were highly charged with H_2S, but also that this gas was present in the mines in unusual quantities. I was also informed by Captain Pill, then manager of the Hancock Mine, that, on one occasion, some men who were working on the black copper ore were for a short time driven from their work by a blower of sulphuretted hydrogen. Another indication of the process by which these deposits of secondary mineral are produced is furnished in the fact that, wherever the walls, *d*, of the deposits were crossed in the ore-bearing horizon by a fracture having a downward inclination, the fissure was invariably filled with copper ore of the class constituting the layer *b*. As before stated, the bottom of the bed of copper marks the limit of the decomposition of the vein, and beneath this line the ore exists in its original condition. The depth to which decomposition of the outcrop has extended is variable, but is nearly identical with that at which water is first found. On the ridges the depth of the gossan may average from eighty to ninety feet, but in the valleys the depth is not more than thirty feet. At one place in the Hiwassee Mine the body of black ore was forty-five feet in width, and Professor Whitney estimated its average thickness at two feet, although in many places it was much thicker.

At first the facility with which this ore could be mined, neither deep shafts nor timbering being required, enabled large quantities to be forwarded to Boston and elsewhere, in addition to that which was smelted upon the spot; but the beds of black ore became gradually exhausted, and at length nothing but the unaltered pyritic ore, *c*, remained. This has, at various times, been worked to considerable depths, but the results obtained do not, as a whole, appear to have been remunerative.

Dr. Hunt regards the Ducktown deposits as fissure veins, thus disagreeing with the opinions of Whitney and Credner, who believe them to be lenticular masses. Dr. Hunt has, however, had the advantage of a great additional development of the underground workings and also of explorations by the diamond drill, and he declares these deposits to possess a banded structure with interstitial spaces, and that they contain vugs characteristic of deposits posterior in origin to the enclosing rocks. The most recent observations on these deposits are by Carl Henrich,[1] who seems to hold that the ores were deposited along fault fissures cutting the stratification of the country rocks at an acute angle, the fissure plane forming always the east wall, which is or was the hanging wall of the deposit. The places of the present deposits were originally occupied by pyroxenic rock; at the time of the uplift of the Appalachian range this rock was altered, its original constituents being replaced metasomatically by pyrrhotite and chalcopyrite. Finally zinc blende, galena and afterwards quartz, marcasite and pyrites were deposited, and completed the transformation of the pyroxenic rock into the present ores. This writer holds that the greater part of these deposits can be profitably smelted for copper if worked on a large scale, but that the mineral consists so largely of pyrrhotite as to be useless as a source of sulphur.

During the tenth census year only one copper mine was in operation in the State of Tennessee; this was situated in Polk County, gave occupation to four men, and produced 294 tons of ore, of which the percentage is not given.

According to Whitney, copper ores have been found in various localities in the State of Vermont. Copper pyrites comparatively free from iron pyrites occurs at Corinth, along a line extending about 1,100 yards, and bearing N. 10° W. A considerable quantity of the ore from this locality was formerly sent to smelting works in Boston. During the tenth census year, Vermont contributed from one mine in Orange County, employing 619 men and boys, 28,037 tons of copper ore, equivalent to 1,324 tons of ingot copper, value $469,495.

Copper ores occur in various places in Wisconsin, and among others in the neighbourhood of Mineral Point, where the ore occupies a fissure fourteen feet in width in Lower Silurian limestone. In 1841, in which year Mr. J. T. Hodge made an examination of this region, the fissure, which had been traced for a distance of about a quarter of a mile and to a depth of fifteen feet, was found filled with gossan enclosing lumps of green copper ore, beneath which was a mixture of clay and yellow ore. At that date about seventy-five tons of copper ore had been extracted from this deposit. During the tenth census year, one mine in Iowa County, Wisconsin, produced 62 tons of copper ore, equivalent to 9

[1] *Trans. Amer. Inst. Min. Eng.* March 1895.

tons of ingot copper, value $1,549, and gave employment to seven men.

The total production in the United States east of the 100th meridian was, during the tenth census year, 1,005,955 tons of ore, equivalent to 25,327 tons of ingot copper, worth $8,842,961.[1]

The following table shows the production of metallic copper (in short tons) in the United States during the eleventh census year [2] and during 1894:—[3]

Production of Metallic Copper in the United States during the Years 1889 and 1894.

States.	1889.	1894.
	Tons.	Tons.
Arizona	15,793	22,266
California	78	60
Colorado	585	3,264
Michigan	43,726	57,263
Montana	49,111	91,547
New Mexico	1,843	77
Utah	33	592
Idaho	78	—
Nevada	13	—
Vermont	36	—
Wyoming	50	—
Southern and Eastern States	9	1,219
All other sources	1,673	464
Totals	113,028	176,752

Iron.

Masses of specular and magnetic iron ore of enormous extent occur in the Laurentian and Huronian formations of North

[1] In the *Census Bulletin*, from which the earlier statistics relative to copper have been chiefly derived, the yield is reduced to metallic copper, and its value is given at the mines, or at the point where it is no longer operated upon. In some instances both mining and smelting are carried on by the same establishment; whilst in others the process of reduction is partially carried on at the mine, and the product shipped in the form of regulus. In other cases the ores of copper are mined and shipped without any preliminary reduction. Thus the industry, strictly speaking, embraces both mining and smelting in a way which renders it impossible to separate the two. It follows that the only common unit to which these various products can be reduced is metallic copper, the value of which, to the mine producing it, varies greatly with the expense requiring to be laid out upon it before it reaches the market in the form of metal.

[2] *Eleventh Census of the United States*, "Mineral Industries," 1890, p. 155.

[3] *The Mineral Industry*, 1894, p. 158.

America.[1] Important ore masses of Laurentian age are found in the States of New York, New Jersey and Pennsylvania; especially on Lake Champlain, in the highlands of New York, in New Jersey, and at Cornwall in Lebanon County, Pennsylvania. In the New York and New Jersey highlands, syenitic gneiss contains beds of iron ore, which for many miles follow all the twistings and contortions of the gneiss. Magnetic iron ore is also found associated with the franklinite and red zinc ores of Franklin and Stirling, New Jersey. On Lake Champlain coarsely granular magnetic iron ore, which is sometimes rendered impure by the presence of apatite, occurs in lenticular beds interstratified in gneiss (*see* page 182). The largest of these and the most productive deposit of iron ore in the State of New York is at the Old Bed Mine, in Essex County, which in 1879–1880 yielded 208,416 tons, of the value of $744,344. In 1890[2] the production of the Lake Champlain mines was as follows:—

Port Henry Mines . . .	417,810	gross tons.[3]
Chateaugay Mines . . .	130,398	,,
Crown Point Mines . .	78,737	,,
Miscellaneous	35,000	,,
	661,945	

Another well-known mine in this State is the Tilly Foster Mine, which consists of an irregular deposit of magnetite in gneiss; its annual yield is about 70,000 tons of ore. The total output of iron ore in this State during 1880 amounted to 1,262,127 tons. The number of iron-ore producing States was no less than twenty-three in that year, whilst it had increased to twenty-six together with two Territories in 1889; it will, therefore, be necessary to confine our attention exclusively to a few of the more important deposits. Moreover, many of the characteristic occurrences have already been referred to in the first part of this work.

[1] T. Sterry Hunt, "The Cornwall Iron Mine," *Trans. Amer. Inst. Min. Eng.* iv. 1876, p. 319; J. C. Smock, "The Magnetic Ores of New Jersey," *ibid.* ii. 1874, p. 314; H. Newton, "Ores of Iron," *ibid.* iii. 1875, p. 360; R. Pumpelly and A. Schmidt, "Iron Ores of Missouri," New York, 1873; T. B. Brooks, "Iron-bearing Rocks," *Geol. Survey of Michigan*, 1873, i. p. 9. Much information respecting American iron ores will also be found in Sir Lowthian Bell's report in the special volume of the Iron and Steel Institute, 1890.

[2] Sir Lowthian Bell, *op. cit.* p. 76.

[3] In America iron ore is usually weighed by the statute ton of 2,240 lbs.

The magnetic ores of New Jersey occur in the mountain range in the western part of the State, and occupy an area of 900 square miles, of which the average elevation is about 1,000 feet above the sea level. Excepting the valleys towards the north-western border, which contain magnesian limestone and Hudson River slate, the whole range consists of crystalline rocks closely resembling those of the Laurentian formation of Canada, distinct stratification being nearly everywhere observable. In the State Geological Survey Reports these rocks are described as Archæan, and it is in this crystalline metamorphic series that the magnetic iron ores are found.

In Sussex County, New Jersey, there is an unique deposit of franklinite, a mineral much resembling magnetite, but in which part of the iron is replaced by manganese and zinc. This is a valuable ore as a source both of zinc white and of spiegeleisen (*see* page 800).

Deposits of magnetic iron ore pass from New Jersey into Pennsylvania, and are extensively worked at Cornwall, in Lebanon County. The Great South Mountain belt is composed of Laurentian rocks, in which are found the characteristic ores of the Highlands of New Jersey, New York and the Adirondacks; whilst Pennsylvania now produces large quantities of these ores, although the great area of ore-bearing Laurentian rocks within her borders still remains comparatively unexplored.

Another class of crystalline iron ores, chiefly magnetites, appears to belong to a distinct ore-bearing horizon, and is found in Pennsylvania along both borders of the Mesozoic Sandstone formation. These ores were referred by Professor H. D. Rogers to what he designated "Primal Slates," which he regarded as the lowest member of the Palæozoic series, though, by some later observers, the Cornwall Mine and certain related deposits west of the Susquehanna have been referred to the Mesozoic sandstones.

The area of ore exposed at the remarkable deposit of magnetite in the Cornwall Mine (*see* also page 49) measures about 4,000 feet in a direction nearly east and west, with a transverse breadth of from 400 to 800 feet, and includes three hills, separated by two valleys running north and south. These hills are due to a great ridge of eruptive rock, apparently dolerite, which, although now broken through by the valleys, was probably once continuous, and, having a curved form, has evidently served to protect the ore-bearing strata, which both on the east and west have been eroded and swept away in past geological ages. The ore is found in nearly horizontal beds, sometimes slightly contorted, and associated with layers of a greenish granular silicate, approaching hornblende in composition, and, more rarely, with a chloritic mineral or with serpentine. Besides these minerals, iron pyrites, which is sometimes cobaltiferous, copper pyrites, malachite and red oxide of copper are occasionally met with. The facilities for mining are very great, the horizontal layers being worked in successive benches, forming wide terraces on the hill side, accessible to railways and locomotives. Into the middle hill two borings have been sunk to depths respectively of 240 and 335 feet below water level, the whole distance being in iron ore. The strata here offer but gentle inclinations, so that these measurements do not materially exaggerate the real thickness of the immense mass of ore lying beneath the surface. The Cornwall Ore Bank has been one of the most productive iron mines in the United States, and in 1880 produced no less than 280,000 tons of ore, worth $500,000, and employed 135 miners. In 1889 it produced 769,020 tons, its total production up to that date having been over ten millions of tons.

But few localities from which iron ores are obtained in the United States possess a higher degree of interest than the deposits in the Archæan rocks of Missouri, amongst which the masses, chiefly of specular iron ore, worked at Iron Mountain and Pilot Knob are most conspicuous. There are also numerous beds of brown hæmatite in the Palæozoic strata capable of furnishing large quantities of good ore, some of which are being more or less actively wrought.

The Iron Mountain, Saint François County, is the largest deposit of iron ore in Missouri, and is surrounded by hills composed mainly of the normal brown porphyry of the district. A zone of red porphyry frequently mixed with iron ore runs along the northern side of the Iron Mountain, and separates the ore deposit from the brown porphyry on the other side. In the eastern portion of the zone the porphyry is partially decomposed, whilst at one point, near its contact with a blue porphyry, it occurs in distinct layers several inches in thickness, and has been sometimes mistaken for a limestone. The whole surface of the Iron Mountain is covered with surface ore of a similar character to that of the deposit itself. The main body of the hill consists of a loose clayey mass of decomposed porphyry, known as *bluff* (the mullock of Australian miners), which is cut into two nearly equal portions by a vein of specular iron ore of from forty to sixty feet in thickness, striking N. 53° E. This vein is known as the *backbone* of the Iron Mountain, but the *bluff* also contains numerous veins of from half an inch to ten feet in thickness, crossing the rock in various directions. The limits between these veins and the country rock are sharply and well defined. The ore of the Iron Mountain is very pure and almost free from mechanical admixtures of foreign matter. Certain extraneous substances, however, occasionally occur in it, such as fragments of porphyry, with crystals of apatite and quartz. The ore contains, on an average, 67 per cent. of iron.

In the accompanying section of Iron Mountain,[1] Fig. 123, *a* represents country rock, *b* iron ore, and *c* a fault.

In 1879–1880 the Iron Mountain employed 300 miners, and

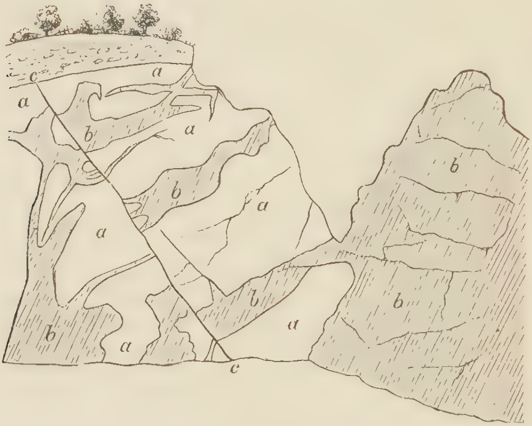


Fig. 123.—Iron Mountain; vertical section.

produced 144,153 tons of ore, worth $1,061,801 ; a value greater than that of the production of any other mine in the State.

Pilot Knob (*see* also page 49) is a conical hill of nearly circular form, having a diameter at the base of about one mile. The rock is composed chiefly of more or less massively bedded porphyries, porphyry-conglomerates, and beds of hard specular iron ore, all of which are somewhat tilted. Their strike is about N. 50° W., and their dip towards the S.W. The top of the Knob consists of stratified porphyry-conglomerate, with a thickness of 140 feet. This conglomerate is made up of pebbles of porphyry cemented together by iron ore, and also contains frequent independent layers and bodies

[1] Pumpelly and Schmidt, "Iron Ores of Missouri," *Geological Survey of Missouri*, 1873, p. 10.

of ore. The ore bed lies at the bottom of the conglomerate series, has a vertical thickness of forty-six feet, and is divided into two beds by a slate seam varying from ten inches to three feet in thickness. This seam, which is very persistent, lies thirty-one feet above the floor of the lower ore bed. The upper ore bed is more variable in thickness, having a regular floor, but no well-defined roof. This bed of ore extends over an area of about 200,000 superficial yards. The Pilot Knob ore differs somewhat from most other specular iron ores in its colour being either steel gray or pearl gray, with a very marked tint of blue. Its lustre is faint and scarcely submetallic, whilst the structure is either crystalline or granular. The ore from below the slate seam contains an average of 60 per cent. of iron whilst that above it averages about 53 per cent. of that metal. During the tenth census year, Pilot Knob produced 52,761 tons of iron ore, worth $115,993, and gave employment to 410 miners.

In the decomposed porphyry of Iron Mountain the ore often occurs in detached masses, which may possibly be segregations from a state of general diffusion throughout the rock. At Pilot Knob, on the contrary, the ore is distinctly bedded, and, although regarded by some who have studied the deposit as an impregnation of bedded porphyries, it is more probably a highly metamorphosed stratified deposit of iron ore. The extensive occurrence of beds of red hæmatite, known as *fossil ore* of Clinton (Upper Silurian) age, has already been described (*see* page 48). These ores are known over no less than nine States, namely, Wisconsin, Ohio, Kentucky, New York, Pennsylvania, Virginia, Tennessee, Georgia and Alabama.

The Huronian rocks of North America contain large masses of valuable iron ores, particularly in the Southern Atlantic States, and on the South shore of Lake Superior. In the Southern States the rocks containing the pyrites beds of Ducktown also enclose beds of magnetite, but they are of comparatively little industrial importance. On the other hand, the Huronian deposits of the Lake Superior region are the most productive in America. The iron-bearing rocks of Lake Superior (*see* also page 46) correspond to the Huronian system of Canada, and consist of a series of extensively folded beds of diorite, quartzite, chloritic schists, clay slates, mica schists, and graphitic shales, amongst which are intercalated extensive beds of several varieties of iron ore. One of the most extensive, regular, and typical deposits of ore in the whole region is at the Champion Mine, thirty-three miles west of Marquette. The strike is here a few degrees S. of W., the dip 68° N., and the general form of the deposit that of a huge lenticular mass. The eastern portion of this is a black magnetic ore, whilst the western consists of a specular slaty ore containing some magnetite. Minor irregular deposits of pure ore, banded ore and quartz, together with magnesian schists, alternate and form a comparatively regular deposit. Overlying the ore on the north side is a hanging wall of gray quartzite, and immediately south of it is a banded quartzose rock containing oxide of iron. Next towards the south, and overlying the whole formation, is a bed of diorite. In 1880 this mine produced 99,609 tons of ore, worth $355,748, and employed 350 miners. Granular and compact varieties of magnetic iron ore occur at the Michigamme Mine. The ore bed is from seven to thirty-five feet in thickness, and extends for a great distance. The production during the census year was 66,158 tons, worth $212,652, and 197 miners were employed. The most productive undertaking, working deposits of a similar class, in this region is the Republic Mine, which in 1880 produced 224,000 tons of ore, worth $896,000, and employed 600 men. This is one of the largest masses of ore in the United States.

One of the most extensive, productive, and geologically interesting deposits in the Marquette Region is the Lake Superior Mine. The structure of the eastern half of this deposit is more complicated than that of any other in the district, and some questions connected with it still remain unsolved. In the western half is an ore-basin or trough, which abruptly narrows towards the west. The outcropping edges of this basin diverge rapidly, and its bottom falls in the same way, showing the deposit not to be a vein but a stratified bed similar to those of the enclosing rocks. In the eastern half there has been such a gathering together, crumpling, squeezing, and breaking up of the strata, as to nearly obliterate the stratification, and, instead of the quartzite hitherto found overlying all these deposits of rich ore, there is here a magnesian schist. The Lake Superior Mine produced, in 1879–1880, 215,930 tons of iron ore, worth $771,180, and employed 542 men.

The centre of the Menominee iron region is about fifty miles south-west of Marquette, and the same distance north of Menominee. The ores in this region occur in two parallel belts running east and west, separated by a broad granitic area. The southern belt is probably the most regular, and one of the most extensive iron deposits on the Upper Peninsula. Like their equivalents in the Marquette region, the ore strata of the Menominee district usually conform in their strike with the general trend of the beds, and dip at high angles. In the tenth census year the county of Marquette, Michigan, alone produced 1,374,812 tons of iron ore, a total more than double that of any other county in the United States, or 17·25 per cent. of the entire production of the country. Other important deposits occur in the Mesabi, Gogebic and Vermilion ranges, all of which form part of the Lake Superior district. The following table[1] shows the shipments from each of five divisions of that district during 1894 :—

	Tons.
Marquette Range	2,058,683
Menominee Range	1,139,273
Gogebic Range	1,810,290
Vermilion Range	948,514
Mesabi Range	1,792,172
Total	7,748,932

Brown hæmatite is widely distributed in the United States, large deposits of this mineral occurring in the Palæozoic limestones of Tennessee, North Carolina and North-western Georgia. The lignites of New Mexico, Colorado and Montana are often accompanied by brown hæmatite resulting from the decomposition of clay ironstones. This is also the case in Alabama and the Appalachian region, and amongst the Carboniferous iron ore deposits of Ohio, Indiana and Kentucky. Limonite occurs in dolomite associated with zinc ores in Arkansas, and Texas is also abundantly supplied with ores belonging to this class. In the latter State flat-lying deposits of brown hæmatite, of comparatively recent age, which may best be classed as bog iron ore, are extensively worked near New Birmingham. The principal deposit of spathic iron ore in the United States is at Roxbury, Connecticut, where, in association with quartz, it occurs in a vein traversing gneiss. Blackband ironstone is of subordinate importance in America, but has been found in the Coal-measures of Western Pennsylvania. Earthy carbonates of iron ore are abundant in Pennsylvania, Western Virginia, and Ohio. The following table shows the quantity of

[1] *The Mineral Industry*, iii. 1894, p. 378.

each kind of ore raised in the United States in the years 1880, 1889, and 1894:—

Table showing the Quantities of various kinds of Iron Ores produced in the Years 1880, 1889, and 1894.

Ore.	1880.	1889.	1894.
	Long tons.	Long tons.	Long tons.
Magnetite	2,134,276	2,506,415	1,280,000
Red Hæmatite . . .	2,243,993	9,056,288	8,660,000
Brown Hæmatite . .	1,918,622	2,523,087	1,820,000
Spathic ore	823,471	432,251	120,000
Totals	7,120,362	14,518,041	11,880,000

In the following table the various iron-mining States are arranged in the order of their production:—

Production of Iron Ore in the United States during the Year 1879–1880.[1]

	Name of State.	Number of counties reporting.	Number of establishments.	Total product. Tons of 2,000 lbs.	Value of Product.	Total number of employés.
					$	
1	Pennsylvania . .	34	358	2,185,675	5,517,079	8,733
2	Michigan . . .	2	43	1,834,712	6,034,648	5,562
3	New York. . .	12	78	1,262,127	3,654,422	4,675
4	New Jersey . .	6	109	757,372	2,910,442	4,811
5	Ohio	8	30	547,303	1,269,530	1,716
6	Missouri . . .	8	48	386,197	1,674,875	1,893
7	Alabama . . .	10	17	191,676	201,865	738
8	Virginia . . .	9	26	182,326	439,886	939
9	Maryland . . .	5	13	139,628	421,691	329
10	Tennessee . . .	12	34	104,465	147,181	552
11	Georgia . . .	3	7	91,416	143,622	342
12	Kentucky . . .	4	5	64,809	165,905	325
13	Massachusetts .	1	9	62,637	226,130	382
14	West Virginia .	6	8	61,216	101,557	266
15	Wisconsin . . .	2	2	41,440	73,000	62
16	Connecticut . .	1	4	35,018	147,799	200
17	Oregon	1	1	6,972	4,669	14
18	Maine	1	1	6,000	9,000	20
19	Texas	1	—	3,600	8,100	—
20	North Carolina .	6	9	3,318	5,285	47
21	Delaware . . .	1	2	2,726	6,553	47
22	Vermont . . .	1	1	560	2,750	15
23	Indiana	1	—	513	1,018	—
	Totals. . .	135	805	7,971,706	23,168,007	31,668

[1] *Census Bulletin*, No. 270.

A small amount of ore raised in Colorado is omitted, as it is used as a flux, and does not, as yet, affect the iron manufacturing industry. In several of the States, especially Texas and Indiana, soft ores are obtained from surface diggings. These are raised by farmers, during the intervals of agricultural employment, and the product drawn by farm teams to the nearest furnace and sold.

The following table[1] shows the amounts and values of the iron ores produced in each State and Territory of the Union during the eleventh census year:—

PRODUCTION AND VALUE OF IRON ORES IN 1889 BY STATES AND TERRITORIES.

States and Territories.	Weight.	Value.
	Long tons.	$
Alabama	1,570,319	1,511,611
Colorado	109,136	487,433
Connecticut, Maine and Massachusetts.	88,251	265,901
Delaware and Maryland	29,380	68,240
Georgia and North Carolina	258,145	334,025
Idaho and Montana	24,072	158,974
Kentucky	77,487	135,559
Michigan	5,856,169	15,800,521
Minnesota	864,508	2,478,041
Missouri	265,718	561,041
New Jersey	415,510	1,341,543
New Mexico and Utah	36,050	70,956
New York	1,247,537	3,100,216
Ohio	254,294	532,725
Oregon and Washington	26,283	39,234
Pennsylvania	1,560,234	3,063,534
Tennessee	473,294	606,476
Texas	13,000	19,750
Virginia and West Virginia	511,255	935,290
Wisconsin	837,399	1,840,908
Totals	14,518,041	33,351,978

The following table[2] gives the total production of iron ores and of pig-iron in the United States in the years 1890–94. Some of the latter may be made from imported ore, but, on the other hand, some of the ore raised is converted direct into malleable iron, and otherwise not used in pig-iron production:—

Year.	Iron Ore. Tons.	Pig Iron. Tons.
1890	16,036,043	9,202,702
1891	14,591,178	8,279,870
1892	16,296,666	9,157,000
1893	11,587,629	7,124,502
1894	11,880,000	6,657,388

[1] *Eleventh Census of the United States*, "Mineral Industries," 1890, p. 4.
[2] *The Mineral Industry*, iii. 1894, p. 358.

OTHER MINERALS.

Manganese.—Ores of manganese are mined in various States, chiefly in the East. Franklinite, occurring in New Jersey, has already been referred to as a zinc ore; it is also utilised in the manufacture of spiegeleisen. In Virginia irregular masses of psilomelane and pyrolusite occur in beds of clay, the ore being apparently a residual product of the decomposition of some rock, as is often the case with manganese ores. Somewhat similar deposits occur in Arkansas. California, Colorado and Georgia also produce ores of manganese. The production[1] of the United States for the years 1890-94 has been:—

Year.	Weight. Long tons.	Value. $
1890	18,787	158,585
1891	22,437	191,613
1892	18,937	154,582
1893	9,150	60,000
1894	11,735	74,890

Nickel and Cobalt.—These metals are raised, but to a very limited extent. The best known deposit is at Lancaster Gap, in Pennsylvania, where nickel-bearing pyrrhotite occurs at the contact of an apparently eruptive rock with mica schist; other ores, such as millerite, also occur. This mine was closed down about 1891. In Churchill County, Nevada, small fissure veins carrying the arsenides of nickel and cobalt have been worked for some years. At Mine Le Motte, in Missouri, pyrites containing nickel and cobalt is got in some of the lead mines. The amount of nickel produced is uncertain; it would seem that about eleven tons of nickel were obtained from ores raised in the United States in 1893.

Chrome Iron Ore.—The existence of this ore in the United States has been known since about 1823, when it was discovered in Baltimore County, Maryland, and soon after in Pennsylvania, in both of which States it has been mined. About fifty years later it was discovered in California, where it is widely distributed, and whence practically the whole of the United States product

[1] *The Mineral Industry*, iii. 1894, p. 448.

is obtained. It always occurs in serpentine, the extensive development of this rock in California accounting for the numerous deposits of chrome iron ore in that State. In 1894[1] the production was 2,653 long tons, worth $35,125.

PLATINUM together with osmium, iridium, and other metals of the platinum group occur in the gold-bearing deposits of the west, and especially in beach deposits (*see* page 27). About 500 oz. of the crude material, worth some $2,000, were obtained in 1889.

The following table shows the amounts and values of metalliferous minerals, &c., produced in the year 1882 :—

GENERAL SUMMARY OF THE PRODUCTION OF METALS, &c., IN THE UNITED STATES DURING THE YEAR 1882.

Metal or ore.	Quantity.	Value.	
		$	£
Pig iron	4,623,323 tons	106,336,429	21,267,286
Gold	1,572,186 oz.	32,500,000	6,500,000
Silver	36,197,695 ,,	46,800,000	9,360,000
Copper	45,823 tons	16,038,091	3,207,618
Lead	132,890 ,,	12,624,550	2,524,910
Zinc	33,765 ,,	3,646,620	729,324
Quicksilver	4,033,998 lbs.	1,487,537	297,507
Nickel	140 tons	309,777	61,955
Cobalt	—	15,000	3,000
Antimony	60 ,,	12,000	2,450
Manganese ore	3,500 ,,	52,500	10,500
Chrome iron ore	2,500 ,,	100,000	20,000
Total value of metals, &c., produced in 1882		219,922,504	43,984,550

The above table has been compiled from a report[2] by Mr. A. Williams, of the U.S. Geological Survey. In most cases the number of tons of ore mined is not given, but it is stated that 9,000,000 tons of iron ore, worth $32,400,000, were obtained during the year.

The following table shows the production of metals and of certain metallic minerals during the years 1889[3] and 1895[4] respectively :—

[1] *The Mineral Industry*, 1894, p. 121.

[2] *The Mineral Resources of the United States*, Washington, 1883.

[3] *Eleventh Census of the United States*, "Mineral Industries," 1890, p. xv.

[4] David T. Day. "Bulletin of Division of Mineral Resources." *Mining Journal*, 1896, p. 1,099.

SUMMARY OF THE PRODUCTION OF METALS, &c., IN THE UNITED STATES DURING THE YEARS 1889 AND 1895.

Metal or ore.	Units of weight.	Quantities.		Values.	
		1889.	1895.	1889. $	1895. $
Pig iron	Long tons	7,603,642	9,446,308[1]	20,000,000	105,198,550
Gold	Troy ounces	1,590,869	2,254,760	32,886,744[2]	46,610,000[2]
Silver	,, ,,	51,354,851	55,727,000	66,396,988[3]	72,051,000[3]
Copper	Short tons	231,246	190,553	26,907,809	38,682,347
Lead	,, ,,	182,967	161,440	16,137,689	10,655,040
Zinc	,, ,,	58,860	89,686	5,791,824	6,278,020
Quicksilver	Flasks of 76½ lbs.	26,484	36,104	1,190,500	1,337,131
Nickel	Pounds	252,663	10,302	151,598	3,091
Antimony	Short tons	115	450	28,000	68,000
Platinum	Troy ounces	500	150	2,000	900
Manganese ore	Long tons	24,197	9,547	240,559	71,769
Chrome iron ,,	,, ,,	2,000	1,740	30,000	16,795
Cobalt oxide	Pounds	13,955	14,458	31,092	20,675
Pyrites	Long tons	93,705	99,549	202,119	322,845
Total value of the production in 1889				269,996,922	—
,, ,, ,, ,, 1895				—	281,316,163

The commercial value of silver is about one-half of its coining value.

DOMINION OF CANADA.

CANADA.

The principal metallic and metalliferous productions of Canada are gold and silver, with copper, nickel and iron ores; but various other minerals, such as iron pyrites, blende and galena, likewise occur in considerable quantities, as does also apatite, which is mined for the manufacture of artificial manures. Although, however, these minerals sometimes occur in comparatively large quantities, Canada can scarcely be regarded as a metalliferous country of exceptional richness.

GOLD.—The existence of gold in the sands of the Chaudière Valley was first made known in the year 1835 by Lieutenant Baddeley, R.E., and since that period repeated examinations have shown that this metal is by no means confined to the district in question, but that it exists in the superficial deposits of a wide region on the south side of the St. Lawrence, extending

[1] Representing 15,957,614 tons of iron ore, worth at the mines $18,219,684.
[2] Coining value $20·6718 per oz. [3] Coining value $1·2929 per oz.

from the St. Francis to the Etchemin Rivers, and from the first line of hills on the north-west to the limits of the province on the south-east. The original source of the gold would appear to be the crystallised schists of the Notre Dame Range, the materials derived from the disintegration of these rocks not only constituting the superficial material among the hills of this range, but also spreading over a considerable area to the south of them. The same gold-bearing rocks may be traced in a south-westerly direction, along the great Appalachian Chain, to the Southern United States. Gold has also been found in Canada associated with galena, blende and pyrites, enclosed in well-defined quartz veins intersecting slates which are believed to be of Silurian age. At Nutbrown's Shaft, situated in the township of Leeds, masses of gold, each weighing several dwt., were found associated with copper glance and specular iron ore, in a vein mainly consisting of a ferruginous bitter spar; small scales of the same metal have also been found in the enclosing country rock. The rocks of this locality belong to the Quebec group, but the precious metal has rarely been found in place, and in Canada the working for it has been almost entirely confined to various superficial deposits of clay, sand and gravel.

Gold is found very generally disseminated throughout the alluvial deposits of the region of which the limits have been roughly defined above, and is not restricted to the river beds, as the forces which distributed the auriferous gravels were evidently anterior to the formation of the present water-courses of the country. When the lighter portions of the gold-bearing gravels have been removed by washing, the residue is found to contain a large quantity of black ferruginous sand, consisting of a mixture of magnetite, ilmenite, chromite and hæmatite, with occasional small crystals of garnet, rutile and zircon. The grains of gold are sometimes angular, but are more frequently much water-worn, and vary in size from nuggets weighing several ounces to the finest dust-like scales.

Gold has been found in the St. Francis River from the vicinity of Melbourne to Sherbrooke, in the townships of Westbury, Weedon and Dudswell, and on Lake St. Francis. It has also been discovered on the Etchemin, and on the Chaudière and nearly all its tributaries, from the seigniory of St. Mary to the frontier of the State of Maine, including the Bras, the Guillaume, the Rivière des Plantes, the Famine, the Duloup, and the Metgermet. Several attempts to work auriferous alluvial deposits have been made in the seigniories of Vaudreuil, Aubert-Gallion, and Aubert de l'Isle, but have all been successively abandoned. The country people, however, still attempt, from time to time, the washing of the gravel, generally by means of a pan, and are occasionally rewarded by the discovery either of a little coarse gold or of a small nugget. In the years 1851 and 1852 an experimental gold-washing on a somewhat considerable scale was carried out on the Rivière du Loup, near its junction with the Chaudière The system of washing adopted closely resembled that employed in Cornwall for tin-streaming, but during the summer months the supply of water was occasionally very limited. In this way about three-eighths of an acre were washed away yielding 105 oz. 7 dwt. of gold, of which eight oz. were in the form of fine dust mixed with about a ton of black iron sand, the residue of the washings. Several nuggets weighing over an ounce were obtained, and the total value of the gold collected was $1,829, whilst the expenditure amounted to only $1,143, leaving a gross profit of $686.

In 1852 about five-eighths of an acre of gravel were washed near this locality, and the total amount of gold obtained was 144 oz., valued at $2,496. Of this quantity 15 oz. 7 dwt. were in the form of dust mixed with iron sand, whilst another portion was in the form of nuggets. Nine of the largest of these weighed, together, 23 oz. 8 dwt.; of these the smallest weighed 11 dwt. and the largest 6 oz. 7 dwt. A little platinum and iridosmine were also obtained, but the quantity of these was small. The profit resulting from this operation amounted to $608, but a portion of the expenditure was for the construction of a wooden flume for bringing water from a distance of about 900 feet. As this would be available for several successive years, a proper allowance made for it would increase the profit to about $680. It consequently appears that from an acre of gravel having an average thickness of two feet there was taken gold of the value of $4,323, whilst the cost of labour, after deducting all expenses not directly incurred in gold-washing, was $2,957, leaving a gross profit of $1,366. The fineness of the gold-dust obtained was 871.[1]

The rocks upon which the gold-bearing gravels of Lower Canada usually repose contain various reefs or bands of quartz, which generally follow the direction of their stratification, namely north-east and south-west.

Although these veins present numerous outcrops, both they and their enclosing rocks are more frequently concealed by a covering

[1] *Geological Survey of Canada: Report of Progress*, Montreal, 1863, p. 741.

either of vegetable soil or of superficial drift. These veins would appear to be most plentiful in the slates and sandstones of the Quebec group, but their thickness and aspect are extremely variable. The quartz is generally white, but is sometimes coloured by oxide of iron resulting from the decomposition of pyrites, which often leaves cavities, imparting to the mass a somewhat cavernous structure. Some of these veins are, on the one hand, composed almost entirely of quartz, whilst others, on the other, contain various metallic sulphides, such as iron pyrites, chalcopyrite, galena, blende, &c., with frequently a little gold. The auriferous quartz veins of Lower Canada exhibit no unusual features, and it is believed that at the present time none of them are being worked for gold, although preparations have recently (1892) been made for erecting a small stamp mill near the junction of the Du Loup and Chaudière rivers.

Mr. A. Michel, who reported in 1866 upon the gold-fields of Lower Canada, states that the acquisition by American companies of a great part of the auriferous lands along the borders of the rivers Chaudière, Famine, Du Loup, and their numerous tributaries, as well as the sale made by the Messrs. De Léry to another company of the mining rights of the seigniory of Vaudreuil (Beauce), might have been expected to have given an impulse to the working for gold in this district. Such, however, had not been the case, none of the companies, since their organisation, having undertaken any serious explorations of their properties, whilst at the same time the country people had abandoned their search for alluvial gold, and the influx of strangers (who came there for the same purpose in great numbers in 1864) had entirely ceased in 1865.[1] After a long period of stagnation, active work was resumed in the Chaudière gold district in 1892. On the Gilbert River, pay gravel, six feet thick, and averaging $75,000 per acre in value, was opened up during that year.[2] The entire province of Quebec produced 721 oz., worth $12,987, in that year. The best year in this district was 1881, when gold to the value of $56,661 was won; then the output rapidly fell off, till it was worth only about $2,000 in 1885, and it continued to average about this amount up to the end of 1891, when it suddenly rose again to the figure above given.

A belt of gold-bearing quartz veins is stated to occur thirty miles north of Belville, in the township of Marmora, Ontario.

[1] *Geological Survey of Canada: Report of Progress*, Ottawa, 1866, p. 49.

[2] *Geological Survey of Canada: Annual Report*, 1893, p. 143.

These reefs are, for the most part, conformable with the stratification, and contain gold in association with various arsenical sulphides. The Huronian slates, which extend a considerable distance north-west of the head of Lake Shabendowan, are of special interest as containing numerous veins, of which some are auriferous. A large number of these veins has been discovered, all of which have an east-north-east direction in conformity with the strike of the beds. The veinstone consists uniformly of quartz, containing copper pyrites, in which the gold when present is enclosed, or it is disseminated through the quartz in such a state of fine division that its particles cannot be detected by the aid of a hand lens.[1] The veins [2] in the above district, and in many others, *e.g.*, Madvy, Sudbury, and Western Algoma, were attracting a certain amount of attention in 1892, and prospecting was being energetically prosecuted. The production of reef gold was only 365 oz., worth $7,118, but an increase on this figure was expected in the near future; it is said to have exceeded $30,000 in both 1893 and 1894.

Gold mining has not, however, been carried on with any degree of activity in Canada proper, and the annual production of gold is not considerable.

SILVER.—The rocks which immediately surround Thunder Bay, on the north shore of Lake Superior, belong to the so-called "Lower" and "Upper Copper-bearing Series" of Canadian geologists. The relations existing between these two groups have not been satisfactorily determined, and the age of both is still a matter of opinion.

The Upper Copper-bearing Series consists essentially of dolomitic sandstones, reddish limestones, indurated red and yellowish marls, red sandstones, and conglomerates with interstratified traps. They have generally been regarded as corresponding either to the Potsdam Sandstone or to some of the lowest members of the Lower Silurian formation, but Mr. R. Bell, of the Geological Survey of Canada, some years since put forward the opinion that they are really of Triassic or Permian age. This view of the question is not, however, generally accepted.

The Lower Copper-bearing Series is well exposed on the north shore of Thunder Bay, and extends beyond its limits as far westward as the mouth of Pigeon River. The series consists, in ascend-

[1] H. Alleyne Nicholson, "On the Geology of the Thunder Bay and Shabendowan Mining Districts," *Quart. Jour. Geol. Soc.* xxix. 1873, p. 16.

[2] *Geological Survey of Canada: Annual Report*, 1893.

ing order, of:—(1) green siliceous conglomerates containing pebbles of quartz, jasper and slate; (2) gray and black chert-bands separated from one another by thin courses of dark gray dolomite; (3) black shales and flags with associated hornblende traps; (4) gray argillaceous sandstones and shales. No organic remains have been discovered in any member of the Lower Copper-bearing Series of Thunder Bay. Its entire thickness is probably about 1,500 feet, and the general strike of the rocks varies from, approximately, east and west to about north-east and south-west. The whole series is traversed by dykes of trap, and there are several interstratified beds of that rock.

The Lower Copper-bearing Series is penetrated by numerous mineral veins, of which the majority run along the strike of the beds, having a general east-north-east and west-south-west direction, but there is also a set of transverse lodes of which the direction approaches more nearly to north and south. One of the most important of the series of veins which follow the strike of the stratified rocks and have a general east and west direction, is the Shuniah Vein, which has been worked upon at several points along its course. It is enclosed in the Lower Copper-bearing rocks of the north shore of Thunder Bay, running nearly parallel to the shore, and at a distance inland of from one and a half to two miles. At the Shuniah Mine itself, the vein courses nearly east and west, and is almost vertical; its width is about twenty-two feet, and the veinstone mainly consists of calcite. Quartz and fluor spar are, however, occasionally present, and iron pyrites often occurs in considerable abundance. Silver is present both in the native form and as sulphide, some specimens being extremely rich. This vein is enclosed in hard black shales, but a large mass of hornblendic trap lies about fifty feet to the south; the lode does not, however, exactly conform to the strike of the beds, so that in following it westward a point is reached where the trap forms the foot wall of the vein. Like the majority of the lodes on the north shore of Lake Superior, the Shuniah Vein is of a brecciated character and contains numerous fragments of the country rock. At all points, where it has been opened upon, this vein has been found to contain silver either in the metallic state or in the form of argentite.

Of all the silver-bearing lodes that have been worked in this region the most important is perhaps the Silver Islet vein, situated on a small rocky island immediately south of Thunder Cape. Silver Islet is three-quarters of a mile from the mainland, and is much exposed to storms from the west, south-west, and east. The island measured originally about ninety feet each way, and rose only eight feet, at its highest part, above the level of Lake Superior. The whole of the rock is now enclosed, and is either covered by works and buildings connected with the mine or by newly-made ground. The course of the vein is about N. 35° W., and its dip 85° towards the south-east. Its greatest width is on the north-western side of the islet, where, as is seen in Fig. 124, it divides into two branches, one of which crosses the islet whilst the other keeps on the western side of it under water. The southern part of the latter branch has always carried the richest ore, the northern branch being less rich, whilst the whole of the vein to the westward is almost entirely barren, con-

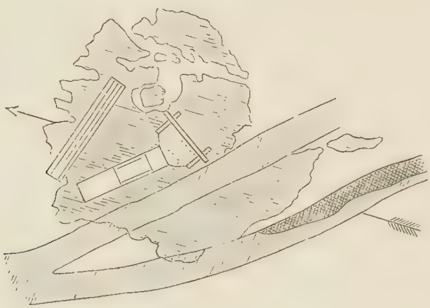


FIG. 124.—Silver Islet; plan.

sisting mainly of large masses of calc spar, with a little quartz and a few cubes of galena containing mere traces of silver. Particles of silver ore are frequently found in small feeders in the country rock between the two branches of the vein, and fragments of the same rock, associated with graphite, are often enclosed in the veinstone.

The metalliferous minerals contained in the veins are native silver, silver glance, tetrahedrite, domeykite, galena and blende, with iron and copper pyrites, and small quantities of the ores of cobalt and nickel. One of the rocks intersected by the vein is a diorite in the form of a dyke, which differs in some respects from the other eruptive rocks of the district. The silver vein is a true lode, cutting through the horizontally bedded schists of Cambrian age as well as the dyke of diorite, which, although an eruptive rock, has not in any way tilted the schists. The deepest workings are 1,160 feet below the surface, and the longest drift on the course of the vein is 1,250 feet in extent; the vein itself has been traced for 9,000 feet.

The fissure in which this vein has been formed is also a line of fault, which has moved the rocks as shown in Fig. 125, which indicates roughly the positions of the rocks and lode below the "5th level." The most productive portion of the vein is marked in Fig. 124 by cross-hatching, and it is worthy of notice that the rocks intersected by the diorite are not highly inclined crystalline slates, but unaltered and almost horizontal flagstones and shales. According to Kemp,[1] it is only where it traverses the diorite that the vein is found to be rich in silver; when this rock forms the walls of the vein, it carries sulphides of lead, zinc, nickel, &c., together with

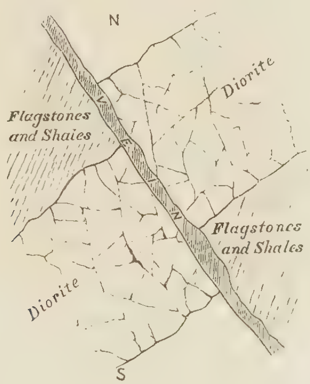


FIG. 125.—Fault, Silver Islet.

native silver, but when the walls consist of flagstones, the fissure contains calcite only. From the date of its first discovery, in July, 1868, to the end of December, 1882, this vein had yielded silver to the value of three and a quarter million dollars, or above £650,000. It is no longer worked.

The Silver Islet Vein has, on one occasion, exhibited a phenomenon which is worthy of notice, and which has been described by Mr. Frue, who was local superintendent at the time of its occurrence. On December 28th, 1875, whilst a party of miners was engaged in drilling a hole in the end of the drift at the "8th level," the drill broke suddenly into a crevice. Water at once commenced to flow, but not in any large quantity, and, not being aware that it was accompanied by an escape of gas, one of the miners took a candle to look at the hole. The gas

[1] *Ore Deposits of the United States*, p. 31.

instantly took fire, sending out a flame of many feet in length, the miners having to throw themselves on the bottom of the level to escape injury, and there remain until the flame had subsided. After having somewhat got over their astonishment they returned to the drift, and when still at a distance of several feet from the end the gas again ignited. They afterwards walked into the level without a light and stopped the hole with a wooden plug. On subsequently applying a lighted candle to the imperfectly plugged hole, however, the gas again took fire, giving a jet of flame about a foot in length, which burned for several weeks.[1]

Native silver occurs in small quantities in several other localities on Lake Superior, as at St. Ignace Island, Spar Island, and Michipicoten Island; the copper ores of the Eastern Townships are likewise often to some extent argentiferous, and galena containing silver is found in various parts of Canada. No lead mines have hitherto been successfully worked in Canada, and the proportion of silver present in the ores is not often large. The output of this district was 225,633 oz.[2] in 1891 and only 41,581 oz. in 1892.

Argentiferous and cupriferous pyrites are worked in the mines of the Capelton district of Quebec; it is calculated that these ores yielded 191,910 oz. of silver in 1892.

Copper.—The copper ores of the Quebec group of Lower Canada occur chiefly as interstratified beds, and are often found in the limestones of this series. These limestones are generally magnesian, and are frequently associated with serpentines and diorites, both of which occasionally contain copper. These rocks are accompanied by slates which in many places are themselves the copper-bearing strata, but they are sometimes so altered as to take the form of chloritic or micaceous schists. The latter are in some cases soft, with a pearly lustre, and are then known as nacreous slates. At other times these rocks are highly siliceous, so that it not unfrequently happens that the copper-bearing bed presents the appearance of a micaceous quartzite. Beds of talcose slate and steatite likewise occasionally contain copper, which is also sometimes found in the red and green argillites of the series. The chloritic schist occasionally becomes calcareous, and gradually passes into an impure limestone. The metal occurs throughout

[1] Thomas Macfarlane, "Silver Islet," *Trans. Amer. Inst. Min. Eng.* viii. 1880, p. 226.

[2] *Geological Survey of Canada: Annual Report*, 1893, p. 131.

these rocks in the form of erubescite, chalcocite, and copper pyrites. Malachite, azurite and cuprite are met with in small quantities, but only near the surface.

Native copper, so abundant in the rocks on the southern shore of Lake Superior, is seldom met with in Eastern Canada; it, however, sometimes occurs in small quantities in certain red slates, and has recently been discovered in boulders of trap rock in Rimouski County. At St. Flavien it is found associated with calcite in an amygdaloidal rock, under conditions closely resembling those which obtain in more western regions. In many parts of the district the copper-bearing beds are traversed by veins which, in some cases, do not contain any metalliferous mineral. Sometimes, on the contrary, they carry large quantities of rich ores, and molybdenite, spathose iron ore and gold have also been found in them. They are seldom continuous for any considerable distance, and the most persistent source of copper ores in this region has been the metalliferous beds. In some cases, as in Sutton and Melbourne, the copper ore occurs in certain beds of dark-coloured slates in a state of such fine division as to be only visible upon close inspection, although the rock may contain from 5 to 10 per cent. of copper. In the magnesian limestones, a schistose structure is sometimes observable, and the copper ore is occasionally distributed through them in the same way as it is in the slates. They are, however, more frequently massive, and the ore often occurs in nodules or as grains irregularly disseminated throughout the rock. In these limestones, as well as in the more schistose strata, there are veins in which the ores of copper are concentrated in a gangue of bitter spar, calcite, or quartz. Sometimes, as at the Acton Mine, ores of copper form the cement of a limestone conglomerate.

In Leeds the copper-bearing rocks are exposed in a greater number of places, and have been more carefully examined, than in any other locality. The explorations at the Harvey Hill Mine are the most extensive which have been made in the Eastern Townships, and have resulted in opening out some very interesting deposits. The copper ores of this locality occur both in veins and in beds, the strata, for the most part, consisting of fine-grained micaceous schists, which from their unctuosity are frequently called talcose, although they are not usually magnesian. A bed of steatite forms, however, one of the members of the series, and bands of a dark kind of argillite are sometimes met with, whilst other beds, either white or light gray in colour, contain nodules of chloritoid and, less frequently, crystals of schorl. The dip of the strata is from N. 10° to 65° W., with an inclination varying from 15° to 30°. The deposits are irregular lenticular veins, which do not coincide with the strata either in dip or in direction. They generally run about 20° E. of N., although the course of a few of them is more nearly east. Their dip, at varying angles, is usually towards the west. Some of these veins, which appear to have filled fissures in the slates, have been traced on the surface for a distance of 100 fathoms. They are occasionally, in their thickest parts, from six to seven feet in width, but gradually thin out both horizontally and in depth. These veins, of which the gangue is principally quartz, more or less mixed with calcite, pearl spar and chlorite, often contain very rich ores of copper, some of them yielding erubescite, or chalcocite, or both, whilst others afford copper pyrites only. Within an area of about thirty acres open cuttings were made upon as many as fifteen distinct lodes, and shafts were sunk upon two others. Notwithstanding that these lodes were sometimes found exceedingly rich, the distribution of copper in them was so uncertain that they were regarded as secondary in importance to the interstratified beds, in which ores of copper are disseminated in the slaty rock. The first of these beds, which are three in number, varies in thickness from two to six feet, and was found on sinking near the summit of the hill at a depth of fifteen fathoms below the surface. Beneath this are some fathoms of barren slates, and then a thin layer of cupriferous rock resting upon a bed of steatite. Another ore bed was subsequently struck at a still greater depth of about twenty fathoms. From the uppermost bed a considerable amount of ore was extracted through Kent's Shaft, at about twenty fathoms from the surface. The second bed, that lying upon the soapstone, should be sixty fathoms from the surface at this point, whilst the lowest will be still deeper by about twenty fathoms, or will have a depth of eighty fathoms from the surface at Kent's Shaft. The copper ores are disseminated through these slates in small masses, often of a lenticular form, running parallel to the bedding of the rocks.

In the accompanying section, Fig. 126, of the Harvey Hill Mine *a*, *b*, and *c* represent the three cupriferous beds, *d*, quartz veins or lodes, and *e*, Kent's Shaft with its various cross-cuts.[1]

In stoping to the west of Kent's Shaft an unusal phenomenon attracted attention, and was at first ascribed to the presence of an ordinary bunch of ore. This is described by Mr. J. Douglas, jun.,

[1] *Geol. Survey of Canada: Report of Progress*, Montreal, 1863, p. 727.

as having first broken through the floor of the bed and appearing as though it had discharged its cupreous solutions into the lowest layers of the slates. As it was followed in stoping, it worked its way up through the slates, and assumed the features of a lode with well-defined walls, terminating in the bed, into which it appeared to have poured its contents. The course of the copper ore, bitter spar and calc spar, as they penetrated from the lode amongst the slates, could be readily traced, and Mr. Douglas is of opinion that the bed had derived its metalliferous constituents from the veins. He adds that subsequent observations tended to strengthen this opinion.[1] The observations of Mr. Douglas, and the conclusions to which he has arrived are of great interest, and are worthy of due consideration; but, after having, on two occasions, spent several

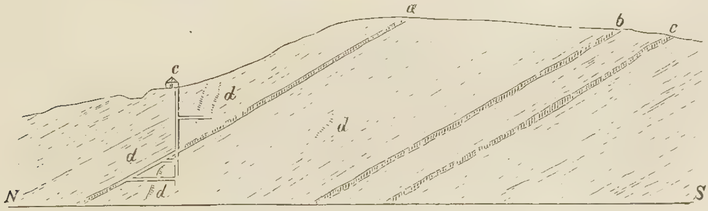


FIG. 126.—Harvey Hill; transverse section.

days at Harvey Hill, I (J. A. P.) am inclined to believe that the various phenomena described may be equally well accounted for upon the hypothesis that the copper ores of the veins were derived from the stratified beds.

Some of the broken ground, consisting of alternate layers of quartz and slate, carries rich bunches of ore, and in some of these masses are found chloritoid, molybdenite and quartz crystals with their angles rounded off as though they had been exposed to the action of a solvent. Specimens of erubescite from this locality are sometimes thickly studded with such crystals, some of them being several inches in length and above an inch in diameter, with their angles almost effaced and their faces dimmed. Although continuously worked during several consecutive years, the copper veins and cupriferous beds of Harvey Hill entirely failed to yield remunerative results, and as a consequence the workings have long since been abandoned; some fresh explorations were undertaken in 1892,

[1] James Douglas, jun., "Notes on the Copper Deposits at Harvey Hill," *Trans. Lit. Soc. of Quebec*, 1871.

but it is not known whether they yielded satisfactory results or not.

At the Acton Mine, limestone is seen dipping to the north-west, the hill south-east of the workings being composed of the massive beds making up the lower portion of the formation. The Copper-bearing Limestone overlies this, and occurs in irregular elongated masses running parallel to the great body of limestone beneath, but varying from it both in thickness and in structure. The upper limestone at this mine is underlain by shales, which often contain more or less copper ore, and are also sometimes to a small extent interstratified with the limestone. With these shales occur beds and masses of diorite which weather to a brownish-yellow colour, in that respect resembling many of the serpentines of the district. Some of the masses of diorite seen in the Acton Mine are 150 feet in length by 50 feet in thickness, but thin beds of the same rock are occasionally interstratified with the slates. In some portions of the diorite masses of calcite are disseminated, thus giving to it the character of an amygdaloid, and imparting a cellular aspect to the weathered surfaces. At other times the copper-producing rock would appear to be a conglomerate containing small pebbles, the longer axes of which lie in the direction of the bedding. Diorites similar in character to those of Acton, and occupying the same stratigraphical position, occur with the Copper-bearing Limestones at Upton, Wickham, Somerset, Nelson, and St. Flavien, and the fact that at the latter place, as well as at Drummondville, they contain copper ores gives to these rocks considerable economic importance.

Portions of a cupriferous slate are sometimes interlaminated with the beds at the base of the limestone, as well as with the underlying diorite. Several dislocations, although none of them of any considerable magnitude, occur at this locality. Some of these appear to follow the strike of the bedding, whilst others occur in two groups of nearly parallel faults, each of which is oblique to the other, as well as to the strata. These dislocations disturb the continuity of the Copper-bearing Limestone, causing the diorite, and even the upper portions of the limestone, to protude into or to interrupt the ore-bearing beds. The underlying limestone is often intersected by quartz veins, which occasionally contain spots of galena or copper pyrites. The workable copper ore is chiefly found in the conglomerate above mentioned, of which it sometimes constitutes the cement; it also occurs in portions of the limestone in the immediate vicinity of, or partly surrounding, the conglomerate. Short irregular veins, containing calcite and sulphides of copper, sometimes enclose a black graphitic substance.

The most important masses of ore occurred in the form of three large bodies, extending over a length of about 120 fathoms, and may have originally belonged to one continuous stratum subsequently divided by dislocations. Of these masses the most northerly, which began with a depth of a few inches, gradually extended to a horizontal distance of forty fathoms with a thickness of forty-five feet. Upon this an open cutting was made to a depth of twenty feet, at which point the limestone had become reduced to a thickness of only four feet. In the north-eastern part of the open working referred to, a shaft was sunk upon the dip of the limestone to a depth of about ninety feet from the surface, where the bed was twenty-four feet in thickness, but poor in copper. At a depth of sixty feet a level was driven about thirty feet westward, where the limestone, which was there sixteen feet in thickness, was cut off by the overlying shale. The ores from this and from the other two deposits were extracted by means of irregular workings, but in the aggregate yielded a large amount of rich copper ores of exceptionally good quality. From the three masses at the Acton Mine,[1] 16,300 tons of 12 per cent. ore were obtained and sent to market; but in the year 1866 all the available deposits had become exhausted, and no exploratory work for the discovery of others having been executed, the mine was abandoned.

The distribution of copper throughout the rocks of the Quebec group is very general, and, according to Sir W. E. Logan, would appear to indicate that this metal was almost everywhere present in the waters from which these strata were deposited.[2]

The copper-bearing veins which traverse the Huronian rocks on the north side of Lake Huron, at the Bruce Mines and several adjacent localities, contain in a gangue of quartz, copper pyrites with, near the surface, chalcocite and erubescite, which are generally massive but in some cases crystalline. Heavy spar, calcite and pearl spar are also occasionally present. The two lodes which have been worked vary from two to four feet in width, and the proportion of ore in them, as compared with the other vein-stuff, was at one time very large. The total quantity of ore obtained from this mine, from the date of its commencement in 1847 to the

[1] *Geol. Survey of Canada. Report of Progress*, Ottawa, 1866, p. 309.

[2] *Ibid.* 1863, p. 515.

beginning of 1863, was about 9,400 tons, averaging 18 per cent. of copper.

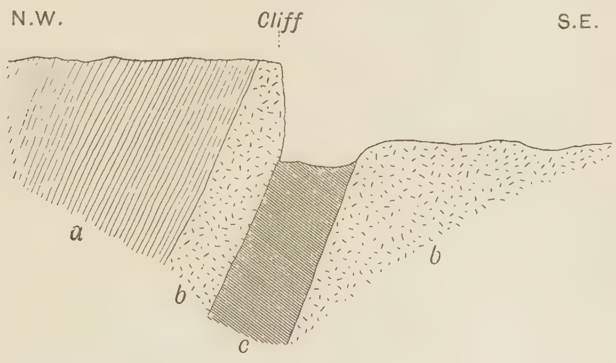
To the north-west of the Bruce Mines are the Wellington Mines, in which the veins closely resemble those of the Bruce, of which they are probably a continuation. The same veins extend into the adjoining property known as Huron Copper Bay. These veins, which were worked for many years with varying success, appear to have become impoverished in depth, and the mines have been abandoned for a good many years.

The Wallace Mine is situated on the shore of Lake Huron, about a mile west of the mouth of White Fish River, on the north side of the bay. The strata here consist of quartzose and chloritic slates dipping northward at a high angle, and include a large mass of greenstone running with the strike of the rocks. Strings and bunches of copper pyrites occur in this locality, both interlaminated with the schists and disseminated in the greenstone. At a distance of a mile and a half further east, and near the base of the hills, two large veins containing iron pyrites with a little yellow ore are said to occur.

On the north side of the island of Michipicoten is a cliff from two to three hundred feet in height in which the greenstone is marked by druses containing analcime and quartz. A soft amygdaloidal bed containing native copper is traceable for some miles along the shore, sometimes beneath the surface of the water in the bays, and at others running a short distance inland. In this bed an attempt was, a few years since, made to work a remarkable deposit of native copper and silver disseminated in grains through hydrous silicate of nickel. The ore was first stamped, and the nickel ore, the value of which was not suspected, was washed away, leaving a metallic residue consisting of a mixture of native copper and native silver. After fusion this residuum yielded an alloy of copper and silver, in which the latter metal was, in one instance, present to the extent of nearly 12 per cent. A shaft was sunk to a depth of about twelve fathoms, but after a considerable outlay the workings were ultimately abandoned. Very little is known relative to the mode of occurrence of this singular deposit, which is said to be associated with calcite.

As mentioned under the head of silver, cupriferous pyrites are mined at Capelton, in the Province of Quebec. In Ontario a good deal of copper is obtained from the copper pyrites associated with the nickel-bearing pyrrhotite of Sudbury; it is obtained in the form of a matte containing both nickel and copper, the proportion of the latter metal being about 27 or 28 per cent. It seems that the whole of the copper produced in this form was shipped to the United States and its amount is given for 1892 as 2,203,795 lbs., valued at $130,758.

NICKEL.—It is only quite recently that Canada has come to the front as a nickel producer; in 1883 some rich deposits of copper pyrites near Sudbury on the Canadian Pacific Railway were discovered, and two years later work was commenced; it was then found that the copper ore was associated with nickel-bearing pyrrhotite, which has since been largely worked. There are several mines, of which the Stobie, Copper Cliff and Evans are the most important. The ore, as seen in the accompanying section,[1] Fig. 127, occurs in large lenticular masses in or closely



Scale about 130 feet to 1 inch

a. Huronian strata. *b*. Diorite. *c*. Ore-body.

FIG. 127.—Section of Ore-Deposit at Copper Cliff.

associated with dykes of diorite that break through the Huronian strata in this district. As far as is yet known, the character of the deposits seems to closely resemble that of the pyrites deposits of Huelva and some of the Scandinavian deposits, except that the ore in Canada carries a high proportion of nickel, namely, some 4 per cent. on the average. These deposits, which are quite irregular in shape and distribution, occur over a length of some eight miles; in the Copper Cliff Mine, the ore has been followed down to a depth of over 700 feet. The following is the estimated

[1] J. H. Collins, "On the Sudbury Copper Deposits," *Quart. Jour. Geol. Soc.* xliv. 1888, p. 834.

amount of metallic nickel[1] present in the matte produced in the respective years :—

Year.	Weight of Nickel.	Value.
1890	1,435,742 lbs	$933,232
1891	4,626,627 ,,	2,775,976
1892	2,413,717 ,,	1,399,956

In 1894[2] the production was 4,223,115 lbs., valued at $818,869.

It is worth mentioning that Sperrylite, an arsenide of platinum, occurs at Sudbury, this being the first place in which platinum has been found in combination, forming thus a true ore. The find has been of no commercial value.

Iron.—The iron ores of Canada possessing economic importance are magnetite, red hæmatite and limonite. Spathose iron ore has not been observed to occur in any considerable quantities. The most abundant iron ore of the province is probably magnetite, which is found only in crystalline and metamorphic rocks. It occurs in the Laurentian series, and in the rocks of the eastern Palæozoic basin. A description of the principal deposits of this ore would occupy much more space than can be devoted to the subject, and, consequently, a few only of the more remarkable will be mentioned.

At Grenville a bed of iron ore, from six to eight yards across, occurs in a gneiss which is interstratified with numerous bands of quartzite. It has been traced for a distance of about 350 yards on its strike, the accompanying beds being cut off at either end by a mass of intrusive syenite. A large deposit of magnetic iron ore likewise occurs in the township of Hull, and is said to have been again met with at a distance of about a mile on the other side of the hill. The ore is found in syenitic gneiss interstratified with a white crystalline limestone containing mica and graphite, and forms a bed about ninety feet in thickness. This appears to have been brought to the surface on the crown of an anticlinal curve, through which appears an underlying bed of crystalline limestone. The ore is coarsely granular and very pure, but is in some places associated with scales of graphite. In the year 1854 this deposit was opened, and was worked for about four years for the purpose of supplying certain furnaces at Pittsburg, Pennsylvania, but in 1858 the workings were suspended on account of the discovery of the

[1] *Geological Survey of Canada ; Annual Report*, 1893, p. 112.
[2] *The Mineral Industry*, iii. 1894, p. 458.

Newborough Mine, which is more conveniently situated for the transport of ores.

An important deposit of magnetic iron ore occurs on an island in Mud Lake, on the Rideau Canal, near Newborough. It forms a bed 200 feet in thickness, running north-east and south-west in gneiss adjoining a crystalline limestone.

At South Sherbrooke a bed of magnetic iron ore twelve feet thick occurs in gneiss, and in the vicinity of Madoc there is another bed from which ore was formerly brought to that village, where it was smelted in a blast furnace and yielded iron of excellent quality. This bed appears to be enclosed in a soft black micaceous rock, and to follow a course somewhat south of east. The greatest thickness of this deposit is thirty feet, but it would probably average about twenty feet.

The magnetite formerly smelted at Marmora was obtained from Belmont, and the deposit, which is generally known as the Big Ore Bed, is commonly said to be 100 feet in thickness. It is not, however, a single bed, but a succession of beds of ore interstratified with layers of talcose schist and crystalline limestone, with which are associated serpentine, chlorite, diallage, and a greenish epidotic rock. The magnetic sands of Moisie have already been described on page 26.

Red hæmatite not unfrequently replaces magnetite in rocks of the Laurentian series, and an important deposit of this ore occurs in the township of McNab. The bed of ore, which is thirty feet thick, rests upon crystalline Laurentian limestone, and is overlain by a magnesian limestone of Lower Silurian age. To the westward this bed has been traced for a distance of about a hundred yards, but in the opposite direction it is concealed by a marsh. The ore is usually compact and has a purple tint, but occasionally it exhibits a finely crystalline structure. Its yield of metallic iron averages about 59 per cent.

The red hæmatite ores of the altered strata belonging to the Quebec group are generally composed of small crystalline scales of the micaceous variety of the red oxide of iron associated with grains of quartz, and occasionally with chlorite. These foreign minerals are present in very variable proportions, so that the schists are sometimes a rich iron ore, whilst at others they are so poor as to possess no commercial value. Several exposures of these iron slates occur in the township of Sutton, and the same ferruginous rocks are again met with in the adjoining township of Brome. A bed of iron slate, two feet in thickness, is said to occur in chloritic schist in Inverness, and it is probable that these ores, which are so abundant in the townships of Brome and Sutton, will be found in many intermediate localities. These slaty iron ores, although generally less rich than those of the Laurentian series, are frequently sufficiently so to admit of their being smelted with advantage.

The more solid varieties of limonite have not hitherto been met with in Canada, but bog iron ore of recent formation is found near the surface of the soil, and is widely diffused throughout the country. On the shore of Lake Erie this ore is found in various localities, especially in the townships of Charlotteville, Middleton and Windham. In the seigniory of Vaudreuil, at Côte St. Charles, there is a deposit of bog iron ore which has been traced over an area of about three acres, and which probably extends much further. This bed of ore varies from four to eight feet in thickness. Bog iron ore is also found at Côte St. Louis, at Côte St. Guillaume in the adjoining seigniory of Rigaud, and in numerous other localities. In the Eastern Townships bog ore occurs in considerable abundance in Stanbridge, and is also met with in the adjoining township of Farnham. The ore from Stanbridge was formerly mined and carried to Alburg, in Vermont, where it was smelted. This ore occurs in the seigniory of St. Vallier, and is found in abundance on Green Island. The St. Maurice forges, in the vicinity of Three Rivers, were for more than a century supplied with bog ore collected in that vicinity, and between the St. Maurice and Batiscan Rivers some important deposits of this ore have been met with. In the vicinity of the village of Industry there are extensive deposits of bog ores, as well as at Batiscan, in the seigniory of Cap de la Madeleine. Reference has already been made to the mode of occurrence of these ores (*see* page 37); they are now being mined somewhat extensively, and smelted at Drummondville and Radnor Forges. The production of ore[1] was 14,380 tons in 1891, and 22,690 tons, valued at $62,385, in 1892.

Although never directly employed as an iron ore, iron pyrites is made use of as a source of sulphur, and is consequently a mineral of much importance in the manufacture of sulphuric acid. Iron pyrites occurs in large quantities in various parts of Canada, and is sometimes associated with small quantities of yellow copper ore. A large deposit of pyrites occurring at Elizabethtown, near Brockville, appears to be an interstratified mass, and has, in some places, a thickness exceeding thirty feet.

[1] *Geological Survey of Canada; Annual Report*, 1893.

In addition to copper this mineral contains traces of cobalt. An important bed of cupriferous iron pyrites occurs at Garthby, and another at Ascot. The pyrites deposits at Capelton, near Sherbrooke, already mentioned, are practically the sole source at present of Canadian pyrites; their production[1] was 67,731 tons in 1891, and 59,770 tons, valued at $179,310, in 1892.

Nova Scotia.

Gold.—Palæozoic rocks extend along the whole of the Atlantic seaboard of Nova Scotia from Seaterie to Cape Sable, whilst the planes of stratification, which have a general east and west course, are mostly parallel with the coast line and with the various axes of upheaval. The leads, or veins, of auriferous quartz, with comparatively few exceptions, conform with the strike of the slates and quartzites, following every plication of the strata and giving rise to an idea, formerly entertained by certain geologists, that they were symphytic beds and not subsequently-formed veins. The quartz veins are, however, by no means confined to the districts in which gold has been found in paying quantities, but those which have proved to be auriferous are usually in the vicinity of the axes of anticlinal folds. On the top of Laidlaw's Hill, in the Waverley district, the lead lies so flat that it is worked long wall, the gold being found chiefly where the quartz has been crumpled together by the folding of the strata so as to form the rolls locally known as *barrels.* These corrugations, which have been followed down on both the northern and southern dips of the vein, on the crest follow the direction of the axis of the anticlinal, whilst the plication of the quartz is marked in the overlying stratum by very moderate undulations only (*see* page 154).

The exact horizon of the auriferous rocks of Nova Scotia has yet to be determined, but it has been suggested by those who regard the leads as being bedded deposits that only the lowest rocks of the series contain gold leads, and that these have been brought to the surface by anticlinal folds. Mr. Poole is, however, of opinion that the lithological characteristics of the several districts point to the existence of three distinct groups enclosing auriferous leads, namely:—1. The lowest, composed of much decomposed and contorted slates and grits cleaving transversely to the planes of bedding. 2. The middle

[1] *Geological Survey of Canada; Annual Report*, 1893.

compact beds, in which quartzite predominates, and of which the cleavage usually conforms to the planes of deposition: numerous quartz leads, some of which are appreciably auriferous, are intercalated with the rocks of this group in the neighbourhood of anticlinals. 3. The upper group, in the extreme western section of the province, consists of fissile slates of an olive-green colour associated with micaceous sandstones, and with at least one bed containing graphite.[1]

In some of the strata chlorite is abundant, but in the principal gold districts this mineral is by no means of frequent occurrence. Sir A. Selwyn, Director of the Geological Survey of Canada, states that some of these sandstones contain pebbles of gray quartzite, and is inclined to believe that they will be found to occupy the position of some division of the Quebec group. Mr. Poole calls attention to the fact that there can be no doubt with regard to the relative age of the gold-bearing veins associated with rocks belonging to this section, since at Gegoggan and Cranberry Head there are veins which, when exposed at low water, are seen to course across the strata and occasionally swell out into masses of from six to eight feet in width; these, within a few feet, contract to so many inches, and again expand and contract. Similar veins have been found to contain gold, and in some instances they have yielded as much as an ounce of gold per ton of quartz.

In Nova Scotia mining operations have not been exclusively confined to the apparently "bedded leads," as rich quartz has been obtained both from "cross-leads" and the so-called "angling leads." Angling leads are true veins, although generally very small; they have usually an east and west course, and cross the strata at small angles. In depth they gradually steal across the beds of slate, but on meeting with quartzite break directly through it to the next stratum of slate and continue to do so in depth. In nearly all cases angling leads are found most productive where passing through quartzite. True cross-leads are of later age than the interstratified beds, and are almost always barren; but in addition to these there are bands of quartz connecting parallel leads, as well as offshoots, which are often called cross-leads, and these are sometimes auriferous. The paying leads are generally small, one eight inches in width being regarded as of good size; thicker ones are however, sometimes worked.

[1] Henry S. Poole, "The Gold Leads of Nova Scotia," *Quart. Jour. Geol. Soc.* xxxvi. 1880, p. 307.

In mining the regular bedded leads, phenomena characteristic of metalliferous veins are frequently observed. The workings on the Union Lead at Waverley, a lead which has been frequently referred to as affording evidence of the bedded origin of these veins, have shown that although the quartz ceases at a certain point the vein fissure nevertheless continues its regular course. In one of the stopes at the same place the quartz formed a roll eight feet in width, and threw off numerous branches into the foot wall. Another characteristic which may be regarded as affording evidence of the vein-like origin of these leads, is, that they sometimes taper out and are continued by splices starting on one side or the other in the wall rock. The most unmistakable evidence of their vein-like origin is, however, afforded by the occasional presences of horses of the rock forming their hanging wall. An example of this occurred in the Barton Lead at Tangier, where a flake of slate ten feet in length was found embedded in the middle of the quartz. This flake had rough edges, and had evidently become detached from a depression in the hanging wall, its course from which was distinctly marked by a series of slaty fragments embedded in the quartz at each end. Fragments of slate are often found in these leads, and in some places laminæ of slate impart to them a ribbon-like structure, suggesting a series of openings of the vein fissure and successive deposits of quartz.

A carboniferous conglomerate has been worked in a small way at Gray's River for the gold which is mixed with the lower portions of the bed and in the runs or hollows in the slate; the bed-rock is also sometimes removed to a depth of from three to four feet for the gold contained in the backs or crevices between the planes of cleavage.

Although of considerable interest to the geologist, the gold mines of Nova Scotia are not commercially of great importance. For many years the annual yield only amounted to about 14,000 oz., whilst the largest produce of any one year was 27,000 oz. More recently, however, the output has again been increased; in 1895 [1] it was 22,113 ounces from 58,082 tons of quartz crushed.

Iron.—Although iron ores occur in various parts of Nova Scotia, the most important deposits hitherto discovered in that province are those at Londonderry in the county of Colchester. The rocks, which are often well exposed in the valleys of the district, consist of gray, blue, and olive-green slaty shales, alternating

[1] *Report of the Department of Mines, N.S. for* 1895, p. 39.

with bands of quartzite and brown felspathic sandstones. The general course of the principal vein is about W. 10° N.; it has a southerly dip of about 80°, and its strike closely coincides with that of the metamorphic slaty shales and sandstones of Upper Silurian age constituting the country rock.

The vein is well seen in the bed of the Great Village River, as well as in excavations in its western bank, which rises abruptly to the height of 325 feet above its level. In the bottom of the stream the vein presents the appearance of a complicated network of fissures penetrating the quartz and slate, and apparently filled with finely crystalline ankerite. In ascending at this point the vein increases considerably in width, as well as in the proportion of iron ore which it contains. At one place where it was cut through its width was found to be not less than 120 feet. It, however, presents the aspect of a wide but very irregular vein. including large angular fragments of quartzite and of a green slate with glistening surfaces. These fragments are especially large and abundant towards the central portion of the vein, where they form a sort of irregular rocky partition. The minerals contained in the vein are ankerite, sideroplesite, calcite, aragonite, specular ore, magnetite, brown hæmatite, and red and yellow ochreous iron ores. A small quantity of heavy spar sometimes occurs in the form of minute crystals lining fissures, and as compact veinlets traversing the ankerite. The whole aspect of the deposit as it appears in the excavation in the river bank is extremely irregular and complicated, which arises, not merely from the broken character of its walls, but also from the number of included fragments of country rock, and from the confused intermixture of the other materials of which the deposit is composed. On the east side of Great Village River the ground does not rise so rapidly as on the western bank, and the vein is not so well exposed, although indications of it can be traced as far as the eastern branch of the stream. On the elevated ground west of the Folly River the vein is again largely developed, and an excavation near that stream shows a thickness of 190 feet of rock on the south side of it. This consists of gray quartzite, with about three feet of black slate, the beds of which are traversed by small strings of ankerite, which increase in dimensions as they approach the wall of the vein.

About seventeen feet of the vein consist principally of ankerite, whilst on the north ten feet of red ore are seen, without reaching the wall. The most extensive workings are upon the western section of the property, and from this part of the deposit nearly the whole of the supply of ore during recent years has been obtained. The principal excavations, however, and those from which the greater part of the ore has been raised, are confined to a length of about 700 feet, where no less than six levels have been driven into the hill at different depths. The upper part of the vein was here filled almost entirely with tolerably pure brown hæmatite of good quality. Referring to this deposit, Sir A. Selwyn remarks that, although there are no good reasons for supposing that at a lower depth than has been yet reached the vein will be found of greater width than it is at present, there is, on the other hand, no reason to apprehend a falling off in this respect. Sir A. Selwyn was unable to verify by personal examination many of the statements respecting the appearance and dimensions of the vein where it had been exposed in old excavations. He was, however, of opinion that the evidence he was able to collect, and the facts he was able to determine, were of such a character as fully to warrant the conclusion that no apprehension need be entertained of any failure of the supply for many years to come.[1] Later investigations have shown that the veins in depth are mostly filled with a mixture of ankerite and sideroplesite,[2] which have been transformed into limonite by the action of meteoric waters in the upper parts of the veins. The following are analyses of these two minerals :—

	Ankerite.	Sideroplesite.
Insoluble siliceous matter	0·57	0·25
Calcic carbonate	53·64	3·14
Ferrous carbonate	23·29	68·47
Manganous carbonate	0·77	2·08
Magnesic carbonate	21·48	26·02
	99·75	99·96

Iron ores occur in many other parts of Nova Scotia; brown hæmatites are well developed in Pictou County, chiefly in Lower Carboniferous limestones, and fossil ores, as already described (p. 48),

[1] *Geological Survey of Canada: Report of Progress*, 1872–3, p. 26.

[2] H. Louis, "On the Ankerite Veins of Londonderry, Nova Scotia," *Trans. N.S. Inst. of Nat. Science*, V. 1879, p. 47.

occur in Annapolis County. The following was the output from these three above-named counties in 1895:—[1]

	Tons.
Colchester County (Acadia Mines) . .	18,532
Annapolis County (Torbrook Mines) . .	29,940
Pictou County	31,157
Total . .	79,629

In this same year pig-iron to the amount of 29,090 tons was produced.

Reference has already been made to the occurrence of copper ores in the province (*see* page 54); none are, however, worked at present. Manganese occurs at Teny Cape and other places in irregular deposits in limestone.

The principal returns from Nova Scotia for the year 1882 were as follows:—gold, 14,107 oz.; iron ore, 42,135 tons; manganese ore, 205 tons.

In 1895 [2] they were as follows:—

Gold	22,112 ounces
Iron ore	79,636 tons
Manganese ore . . .	110 ,,

British Columbia.

For our knowledge of the geology of the gold-fields of British Columbia we are mainly indebted to Dr. G. M. Dawson, of the Geological Survey of Canada, whose able papers on this subject have from time to time appeared in successive "Reports of Progress." [3]

Gold.—The very general distribution of alluvial gold over this portion of British North America may perhaps indicate that its rocks of various ages are more or less auriferous. The most important gold formation, however, consists of a series of talcose and chloritic schists, blackish or greenish-gray in colour, which sometimes become micaceous, and which usually more distinctly exhibit

[1] *Report of the Department of Mines, N.S.* 1895, pp. 53, 83.

[2] *Ibid.* p. 3.

[3] "Report on Leech River," *Geol. Survey of Canada: Report of Progress,* 1876–77, p. 95; "General Note on the Mines and Minerals of Economic Value of British Columbia," *ibid.* p. 103; "Report on Exploration in Southern Portion of British Columbia," *ibid.* 1877 78, p. 153 B, &c.

evidences of metamorphism than do the gold-bearing schists of California. Their precise geological horizon is as yet undetermined, although it is not improbable that they may eventually be found to be the geological equivalents of some of the most productive gold-bearing rocks of California. The most extensive areas of these rocks are found in connection with the disturbed regions west of the Rocky Mountains, known in various parts of their extent as the Purcell, Selkirk, Columbia, Cariboo, and Omineca Ranges. Belts of auriferous rocks of considerable extent, and probably belonging to the same age, however, occur beyond this region, as in the vicinity of Anderson River and Boston Bar, on the Fraser, as well as at Leech River, Vancouver Island, and elsewhere.

The Cariboo district, which was discovered in 1860, has been the most productive and permanent gold-field of British Columbia. It has been described as a mountainous region, but is rather to be regarded as the remnant of a great plateau, with an average elevation of above 5,000 feet, intersected by innumerable streams which flow from it in all directions, and which join either the Fraser River or one or other of its branches. The fifty-third parallel of north latitude passes nearly through the centre of the gold-field, where streams falling rapidly over rocky beds descend into deep and precipitous valleys. With a lessening slope the rock becomes concealed by deposits of gravel, which gradually increase in thickness and extent until the valleys become flat-bottomed with occasional swampy glades, through which the stream flows tortuously with a sluggish current. Lightning and Williams' Creeks have yielded the larger portion of the gold of Cariboo. Both localities are not only rich, but are also specially adapted for deep workings from having a hard deposit of boulder clay extending beneath the beds of the present water-courses, which, to a large extent, prevents the infiltration of surface water into the workings beneath. By regular mining operations the rocky bottom of the valley is sometimes followed below 150 feet of overlying clay and gravel, the course of the ancient stream being easily traced by the polished rocks of its bed as well as by the gravel and boulders filling its channel. The richest lead is usually found in the hollow of the ancient channel, although, by following the rock-surface laterally, paying ground is often met with for some distance on either side. The old streams of Cariboo are found to have followed very nearly the same directions as their modern representatives, often crossing the valleys in various bends from side to side, but never leaving them or running across the modern drainage system as is frequently the case in the deep placers of California and Australia. On Williams' Creek, on which are situated the townships of Barkerville and Richfield, the principal workings are confined to a space of about two and a half miles in length. In this ground not only the deep channel has been worked, but also as much of the side ground as was at the time found remunerative. Many of the lateral creeks and gullies paid remarkably well, and in some places the hill sides, to the height of above 100 feet, have been sufficiently rich to make satisfactory returns by the hydraulic method of mining, which has been extensively introduced into British Columbia.

Although the production of Williams' Creek has always been much less considerable than that of Lightning Creek, Barkerville nevertheless possesses a certain local importance as the centre of a number of outlying mining districts. The mines in the gold-fields of Kootenay, Omineca, and Cassiar, situated on the same belt of auriferous rocks, resemble, in their main features, those of Cariboo. The greater portion of the Gold Range, especially towards the north, is very heavily timbered, and is often so covered with moss, peat, swamp and tangled vegetation as to render prospecting difficult, and the discovery of rich spots a matter requiring much time and labour. Dr. Dawson, however, remarks that the recognised areas of the gold-fields will be very much extended as soon as altered conditions shall have rendered less productive deposits remunerative, when many of those which have now ceased to attract attention will again spring into importance.

In the southern portions of British Columbia gold has been very rarely found *in situ*, but occurs in remunerative quantities in placer deposits in various localities. These generally either lie upon, or in the immediate vicinity of, certain black slaty rocks traversed by quartz veins, from the disintegration of which the alluvial gold appears to have been derived. Similar rocks, undistinguishable in lithological character from those of the typical region, may, it is true, occur on other geological horizons in the district, but no clear evidence of this has yet been obtained. The rocks are generally black or very dark, slaty, or schistose; often more or less calcareous, and not unfrequently micaceous or graphitic; more rarely chiastolitic. Dr. Dawson is of opinion that it is probably to the presence of a small quantity of organic matter in the sediments from which these rocks have been made that their metalliferous character is due. Their fissile structure has subsequently rendered them easily permeable by waters, which have concentrated the minerals of economic value, with quartz and other crystalline materials of secondary origin, in the veins. The rocks, in their more typical localities, appear to be between those of the Cache Creek group (Carboniferous) and the Upper Mesozoic rocks similar in age to the Shasta group of California. They seem to rest conformably on the former series, and even to blend with it, whilst the latter is built up upon their upturned edges. They differ in appearance from the recognised Jurassic rocks of the Iltasyouco, and have yielded no fossils with the exception of some obscure impressions. Whilst a portion of these rocks may represent Jurassic beds differing from those of the Iltasyouco region by reason of the want of volcanic materials, part at least would seem to represent the Triassic period, or even to pass downward into the Upper Palæozoic. They are not very different from the slaty rocks of the continuation of the same mountainous belt in California, which are highly auriferous, and supposed to be, at least in great part, Triassic.[1]

There are, at the present time, no important gold diggings on the lower part of the Fraser River, although it was this region that first attracted the gold miner to British Columbia; a considerable amount of gold is, however, still annually obtained, chiefly by Indians and Chinamen during the portion of the year when the water is low. From the Thompson, near Nicoamen, the first gold known to have been found in British Columbia was obtained, and this locality still continues to yield considerable quantities when the river is low. The Tranquille River, flowing into Kamloops Lake, was worked previous to 1862, and has afforded occupation to a varying number of miners ever since, although it has of late fallen almost entirely into the hands of Chinamen. The gold is, for the most part, scaly, and is often mixed with grains of platinum. At St. Louis Creek, on the lower part of the North Thompson, the gravels were formerly worked for gold. On the South Similkameen, about three and a half miles above Vermilion Forks, gold mining has been carried on for several years, although the number of men employed is not large.

Rock Creek still continues to afford profitable employment to a few men, and gold, in small quantities, has been found on several streams flowing into the Okanagan Creek; of these diggings those on Mission Creek, where the gravels of the flat rest upon Tertiary

[1] *Geological Survey of Canada: Report of Progress*, 1877–78, p. 153B.

beds, have proved the most important. Cherry Creek, a tributary of the Shuswap River, has yielded a considerable quantity of gold, and still gives employment to a few white miners and a much larger number of Chinamen. Although there are numerous quartz reefs in British Columbia, some of which have, by assay, been shown to contain both gold and silver, few of them appear to have been worked.

According to Dr. Dawson, the Leech River, in Vancouver Island, was discovered to be auriferous in 1868. For some time it was generally thought that the district would prove to be a permanently productive gold-field, and houses and stores were erected accordingly. About £20,000 worth of gold is said to have been obtained in a comparatively short time from these diggings, but they are now entirely abandoned. Gold occurs in Queen Charlotte's Island, both in the alluvium and in quartz veins, but has not been extensively worked.

It is estimated that the value of the gold produced in British Columbia during the year 1881 amounted to about £240,000, and that the total value of that metal obtained up to that date since its discovery in 1858 may be taken, approximately, at £9,350,000. The output has steadily fallen since 1863, and was only 23,501 oz., valued at $399,525, or about £80,000, in 1892.[1] To this amount must be added the production of the North-West Territories, which amounted to 5,760 oz., worth $98,006, chiefly from placers in the Yukon and Saskatchewan valleys. Very little quartz mining is carried on, although a little work, chiefly experimental, is being done on the reefs of the Cariboo district.

Silver.—Small nuggets of native silver have been occasionally found in gold placers on the Similkameen and Mission Creeks, besides which a rich silver ore, which is probably freibergite, occurs in small and irregular veins at Cherry Creek. These veins are enclosed in grayish or blackish-gray slates, and the veinstone is principally composed of quartz; assays of this ore have sometimes yielded as much as 658 oz. of silver to the ton. Nodules of argentiferous galena found in the sluice boxes on Cherry Creek, but above the known lodes, have assayed as much as 220 oz. of silver to the ton, and would indicate the existence of veins which have not yet been discovered.

Since about 1890 important discoveries of silver lead have been made in the Kootenay districts, the chief deposits being in the Illecillewast and Slocan sub-divisions.[2] The strata consist of

[1] *Geological Survey of Canada: Annual Report*, 1893.

[2] *Ibid* S. p. 163.

contorted and locally metamorphosed shales, slates and limestones, associated with dioritic and serpentinous rocks. Fissure veins are found traversing these rocks, and, as usual, they form pockets or bunches, and apparently flats, in the calcareous strata. The veins show a banded structure, and carry chiefly argentiferous galena, together with arsenical and antimonial ores of silver, and some copper, perhaps as tetrahedrite and as sulphide. It is said that shipments have in some cases averaged $200 per ton. The mines have hardly passed beyond the experimental stage, and the ore is not yet treated on the spot, but is shipped to the United States to be smelted. The ores produced in 1892 carried silver to the amount of 77,160 oz., valued at $66,935. Great hopes are entertained of the future developments of this region.

OTHER METALS.—On the north side of Copper Island, a band of schist about six feet in thickness exhibits a bright copper stain, and on examination is found to be impregnated with copper pyrites, to the decomposition of which, on the surface, the coloration is due. Fragments of rich copper ore, as well as rounded pieces of native copper, have been found on the Thompson. Native copper has also occasionally been found on the Fraser, and less frequently on the Similkameen. The Hall Mines in the year ending September 30th, 1895, produced and sold copper ores, chiefly yellow, gray, and peacock ores to the value of £7,955.[1]

Bismuth in the form of sulphide, enclosed in thin veins of quartz, has been found on the north-east side of Little Shuswap Lake.

Magnetite occurs in considerable quantities in Cherry Bluff, Kamloops Lake, and on Iron Mountain; it is also reported to exist in a vein several feet in width, in a ravine half a mile below Nicoamen. According to Mr. Richardson, clay-ironstones are of frequent occurrence in the coal rocks of Vancouver and Queen Charlotte's Islands. The nodules vary in weight from less than a pound to above a ton, and he is of opinion that at Baynes Sound Mine a sufficient amount could probably be obtained to supply a blast furnace.[2]

Platinum is produced in some of the placer mines, the total amount produced in 1892 being valued at $3,500.

The following table[3] shows the production of metals and

[1] *Directors' Report for* 1894–95.

[2] *Geological Survey of Canada: Report of Progress*, 1872–73, p. 81.

[3] *First Annual General Report upon the Mineral Industry of the United Kingdom*, 1895, p. 55.

metalliferous minerals in the Dominion of Canada, including Canada proper, Nova Scotia, New Brunswick, and British Columbia, with the North-west Provinces, for the year 1893:—

TABLE SHOWING THE QUANTITY AND VALUE OF METALS, &C., RAISED IN THE DOMINION OF CANADA DURING THE YEAR 1893.

Description.	Weight.	Value.
		£
Gold	51,609 oz.	190,530
Silver	414,975 ,,	66,046
Platinum	?	370
Copper	3,620 tons	179,972
Lead	953 ,,	16,643
Nickel	1,783 ,,	426,647
Zinc	5 ,,	97
Iron ore	111,341 ,,	61,237
Manganese ore	204 ,,	2,971
Ochres	955 ,,	3,639
Pyrites	52,270 ,,	36,088
Total value		984,240

The following is a partial return, in part estimated, of the production of certain of the metals and metallic minerals for 1895:—

ESTIMATED PRODUCTION IN THE DOMINION OF CANADA DURING THE YEAR 1895.

Description.	Weight.	Value.
		$
Gold	—	1,910,921
Silver	1,775,683 oz.	1,158,638
Copper	8,789 tons	949,229
Pig iron	102,797 ,,	238,070
Lead	23,076 ,,	749,966
Quicksilver	—	2,343
Nickel	—	1,360,984
Chrome iron ore	3,177 ,,	41,307
Manganese ore	125 ,,	8,464
Total value (£1,337,500)		6,419,922

NEWFOUNDLAND.

The most important mines in Newfoundland, which is the only portion of British North America not included in the Dominion of Canada, are those of Betts' Cove and Little Bay, situated on the north-eastern part of the island, where the deposits appear to occur in rocks belonging to the Quebec group.

Dr. Sterry Hunt [1] regards the Quebec group as of great economic importance, as it is the principal metalliferous formation of large areas in North America. "To it belongs the gold found along the Appalachian chain from Canada to Georgia, together with the ores of lead, zinc, copper, silver, cobalt, nickel and chromium. The latter metals, particularly chromium and nickel, are constantly associated with the ophiolites and other magnesian rocks of this series, whilst they are wanting in similar rocks of Laurentian age. The deposits of copper ore in East Tennessee, and the similar ores in Lower Canada, belong to this group. The ores of lead, copper, zinc, cobalt and nickel, of Missouri, and the copper of Lake Superior also occur in rocks of the same age, which appear to be pre-eminently those of the metalliferous period." The ore at these mines occurs in deposits under conditions strikingly similar to those known to prevail in Eastern Canada, and to characterise rocks of apparently contemporaneous origin.

There are important copper mines at Betts' Cove, Tilt Cove and Little Bay, where lenticular masses of cupriferous iron pyrites, in metamorphic rocks of perhaps Archæan age, are worked, these deposits resembling in many respects those of Huelva.

The production of copper ores from these mines from the commencement of shipments in 1875 to the end of 1882 was as follows:—

	Tons.
1874, 1875	8,000
1876	18,000
1877	44,000
1878	25,000
1879	25,460
1880	20,920
1881	24,200
1882	16,430
	182,010

The ore consists of a mixture of iron and copper pyrites containing about 7 per cent. of copper, with but little silica, and is

[1] *American Journal of Science*, vol. xxxi. 1861, p.

remarkably free from arsenic. The Little Bay Mines were only opened in 1878, so that all the ore shipped previous to that year must have come from the Betts' Cove Mines only.

In 1893 the production of copper ore and regulus, chiefly from Tilt Cove, was 45,314 tons, valued at £84,408. Iron pyrites to the amount of 37,889 tons, valued at £46,700 was produced during the same year. These mines, owned by the Cape Copper Company, Limited, produced 64,470 tons[1] containing 3·84 per cent. of copper in the years 1894–5.

MEXICO.

The mountains in the extreme south-east of Mexico are mainly composed of porphyry with limestone and clay slate, in the latter of which veins of silver, copper and lead ores frequently occur. Granite forms the foundation of the central table land, but its upper strata exhibit an extensive area of porphyries rich in the precious metals, together with basaltic lavas, trachytes, clay slates, amygdaloids, syenites, serpentines, dolerites, limestones and sandstones. The Cerro del Mercado, in Durango, is said to consist chiefly of iron ore. The mineral products of Mexico are perhaps richer than those of any other country, and include gold, with ores of silver, iron, copper, lead, tin and quicksilver.

Gold and Silver.—Amongst the most celebrated mines are those of Guanaxuato,[2] which were opened by the Spaniards at the beginning of the sixteenth century. Their production of gold and silver, from 1701 to the end of 1865, has been estimated at 521,106,638 pesos, or 2,600 millions of francs. Sedimentary rocks, of which the exact geological horizon has not been determined, contain the celebrated lode known as the Veta Madre. This deposit, which is one of the most important in the world, coincides exactly in strike (45° to 50° N.W.) and dip (45° S.W.) with the bedding of the country rock, and, consequently may be regarded as a bedded lode. The clay slates are probably of Devonian age, whilst the conglomerate beds belong to the New Red Sandstone period. In the Valenciana and Rayas Mines the lode is most productive at the contact of these two rocks, and has a width of 150 yards, with from 90 to 120 yards of ore ground.

[1] *Report of the Directors for* 1895.

[2] E. Tilmann, *Der Bergbau von Guanajuato*, Münster, 1866.

The veinstone consists principally of amethystine quartz and calc spar, enclosing interstratified fragments of country rock. Among the other minerals present, gypsum, spathic iron ore, fluor spar, apophyllite and asbestos are the most common; heavy spar is entirely absent. The curious interpolations of talcose rocks impregnated with silver ore, called *jabones*, which are found in La Luz and in some other lodes, also occur in the Veta Madre. The metals and ores are native gold, native silver, argentite, and, more rarely, stephanite, pyrargyrite, fahlerz, galena and blende. Copper pyrites and iron pyrites are of frequent occurrence, the latter being always argentiferous. Geodes are plentiful, and in them all the above-mentioned minerals occur in a crystallised form. In the lodes of Guanaxuato the ore is first found at a depth of about forty fathoms, and at from 200 to 250 fathoms the ores become so rich in atimony and lead as to be no longer adapted for amalgamation. In addition to the Veta Madre two other systems of lodes are met with in the neighbourhood of Guanaxuato.

1st. At Santa Rosa the porphyry is traversed by lodes containing silver ores, native gold, and quartz.

2nd. The lodes of La Luz traverse diorite in a direction 15° to 45° N.W., and with a dip of from 50° to 70° S.W. The veinstone is quartz and calc spar, with masses of the talcose rock above referred to, impregnated with silver ores, known as *jabones*, which form the principal source of the riches of La Luz.

The rich silver lodes in the grauwacke of Zacatecas, north-west of Guanaxuato, appear to be very similar to the Veta Madre. Fourteen leagues north-west of Zacatecas is the city of Fresnillo,[1] at the foot of a mountain known as the Cerro de Proaño, which is intersected by silver-bearing veins, of which the number is stated to exceed fifty. These are all true veins, enclosed either in grauwacke or Devonian clay slate. They carry three classes of ore, respectively distinguished as *colorados*, *negros* and *azulaques*.

Los colorados, the red ores, are distinguished as carrying chiefly native silver, silver chloride or chlorobromide (*plata verde*), mingled with reddish iron oxides and quartz, rarely with remains of unoxidised ores. In short, the red ores mark the zone of decomposition influenced by the atmosphere and its waters, the depth to which they penetrate varying considerably in different veins. *Los negros*, the black ores, are essentially a quartzose veinstone carrying black sulphides of silver, argentite, stephanite,

[1] B. Silliman, *Sketch of the Great Historic Mines of the Cerro de Proaño at Fresnillo*, New Haven, 1883.

pyrargyrite, &c., with native silver and iron pyrites. *Los azulaques*, or bluish ores, are essentially peculiar to the veins of the Cerro de Proaño, and consist of the same ores found in the adjacent veins, but distributed in the body of the country rock for a distance of from sixteen to thirty-two inches beyond the lode. For this distance the country rock is found to be impregnated with iron pyrites, argentite, horn silver and native silver, in thin coatings. The total value of the silver produced by the Cerro de Proaño mines, from 1853 to 1862, was $9,825,595.

The mining district of Tatatila and Zomelahuacan[1] is seven geographical miles from Jalapa. The district is formed of limestone, greenstone, porphyry and trachyte, and the lodes occur most frequently in the limestone, rarely in the greenstone and porphyry, and never in the trachyte. The lodes, the number of which is very great, are on an average from three to six feet in width, dip at a great angle, and course nearly north and south. Four distinct groups of veins are distinguished, namely :—

1. Auriferous lodes containing native gold enclosed in quartz coloured by iron oxide.
2. Silver lodes containing argentiferous ores in a gangue of calc spar and quartz.
3. Lodes containing argentiferous galena, quartz, and calc spar.
4. Copper ore veins, coursing very irregularly, containing auriferous copper pyrites and variegated copper ore.

The ore masses of La Concepcion Mine, which do not belong to any one of the above groups, as they contain at the same time auriferous quartz, lead, silver and copper ores, are among the most important.

Near Pachuca,[2] twenty-two leagues north of the city of Mexico, is the mining village of Real del Monte. The Sierra de Pachuca at this point is composed of variously coloured porphyries invariably forming the matrix of the ores, these being never found in the younger eruptive rocks which burst through the porphyries. Stratified rocks do not occur in the neighbourhood either of Pachuca or of Real del Monte. The lodes, which are numerous, course nearly east and west, and are, generally speaking, parallel; they usually dip 70° S., but in some exceptional cases their dip is towards the north; cross lodes, coursing from north to

[1] Richter und Hübner, *Zeitschr. f. Berg. Hütt. u. Salinenw.* xxi. 1873, p. 26.
[2] *Ibid.* p. 103.

south, are rare, and have no great thickness. The veinstone chiefly consists of quartz and decomposed porphyry, whilst calcite is of rare occurrence, and heavy spar is still less abundant. Native silver and stephanite are common, whilst pyrargyrite, blende and copper pyrites are comparatively rare. The average percentage is from 0·15 to 0·18 of silver, which contains 0·2 per cent. of gold. The widest lode is that of Arevalo, near El Chico, which is from sixty-four to seventy-five feet in width, but contains much worthless material. The lode of greatest extent is the Veta Biscaina, which may be traced for 5,000 fathoms along its strike, and is perhaps connected with the Veta Madre of Guanaxuato.

The Jocuistita silver mine is situated about 100 miles north of Mazatlan, Sinaloa, at an altitude of 3,500 feet above the sea level. During the year ending 1st June, 1882, 5,500 tons of ore from this mine were smelted on the spot, yielding $1,010,529 of bullion.

Numerous silver-bearing veins also occur in the district of Carmen in Sonora, where they appear to be connected with eruptions of trachytic porphyry. The Alamada and Tirito Company[1] at Promontorios produced in 1895 ore to the amount of 1,890 tons, containing on an average 57·8 ounces to the ton, and worth $115,613. Many other localities might also be named in which silver ores, usually low grade, but very abundant, are mined. Generally speaking, they occur in calcareous rocks, or else connected with eruptive rocks, often trachyte. It would almost seem as though silver ores had formed wherever the physical or chemical characters of the country rock admitted of the action of mineralising solutions.

It is estimated that from 1521 to 1891, Mexico produced silver to the value of $4,000,000,000. It is supposed that the third part of the silver in the world has come from Mexican mines.

The output of precious metals in Mexico in 1881 is officially stated at $29,713,355.[2] In 1880 the production was, gold $989,161, silver $25,167,763.[3]

The following is stated semi-officially[4] as the value of the exports of gold and silver from Mexico between the years 1880 and 1892, the values being expressed in Mexican dollars:—

[1] *Report of the Directors for* 1895.

[2] B. Silliman, *Cerro de Proaño*, p. 12.

[3] C. King, *Production of the Precious Metals*, Washington, 1881.

[4] Luis Pombo. *Mexico:* 1876–1892. Mexico, 1893, p. 125.

	Gold. $	Silver. $
1880–81	1,151,148	17,774,910
1881–82	1,042,031	15,700,704
1882–83	879,747	28,441,212
1883–84	927,300	32,242,770
1884–85	881,526	32,770,900
1885–86	607,467	29,160,835
1886–87	519,084	32,642,785
1887–88	585,651	30,286,247
1888–89	602,762	37,982,948
1889–90	554,202	37,912,848
1890–91	746,838	35,259,131
1891–92	926,932	46,272,391

In 1893[1] the production of gold was 1,964 kilogr., worth $1,305,300, and of silver 1,380,116 kilogr., worth $57,357,600, this latter figure being 27 per cent. of the world's production. Mexico ranks second only to the United States as a silver producer.

The output of precious metals for 1894[2] is given as :—

	Kilogr.	Value.
Gold	6,771	$4,500,000
Silver	1,463,361	$29,640,378

The following table[3] shows the nature and value of the exports of the precious metals, and of substances containing them, for the fiscal year July 1st, 1893, to June 30th, 1894 :—

Argentiferous copper ore	$377,216	
Silver ore	9,023,596	
Coined silver	17,386,338	
Slags	60,590	
Silver bars	3,130,823	
Silver with gold	4,750,720	
Sulphide of silver	757,101	
Argentiferous lead	9,927,324	
		$45,413,708
Coined gold (Mexican)	$135,999	
Gold bars	155,954	
Gold with silver	480,890	
Gold ore	55,799	
		828,642
Total		$46,242,350

[1] *Report of the Director of the U.S. Mint*, 1894, p. 163.

[2] *The Mineral Industry*, iii. 1894, p. 281.

[3] *Ibid.* p. 283 (quoted from the *Boletin Semestral de la Direccion General de Estadistica*).

COPPER.—Copper is principally produced by the well-known Boleo Mine, operated by a French company. The ore, according to Fuchs,[1] occurs in three beds, interstratified with argillaceous tufa and conglomerates, the country being traversed by various eruptive rocks, chiefly trachytes. The beds appear to be tufaceous, and to contain various oxidised copper ores, which occur generally in concretionary spherulites. Work was commenced here in 1884, and operations on an extensive scale about 1887. The output was 6,284 tonnes of copper in 1892, the total copper production of Mexico for that year being only 7,663 tonnes. Copper shipments from Mexico seem to have commenced about 1886, when 163 tons were shipped.

MERCURY.—Mercury has been found in small quantities in various places, frequently associated with rocks of Neocomian age; the most important districts are Guadalcazar and Huitzuco in the State of Guerrero. In the former locality it occurs in calcareous rocks of Cretaceous age, where it forms veins and impregnations, the age of the formation and nature of the deposits being similar to those in California; in 1894 the Guadalcazar[2] district is said to have produced about 2,500 flasks, and Huitzuco about 5,000 flasks. The total production of Mexico for that year is given as 268 tonnes.

TIN.—Tin is said to occur in small quantities in various parts of Mexico, and to have been worked at an early period; the mines in the State of Durango are the most important. In Potrillos[3] a certain amount of stream tin has been got, and cassiterite occurs along the fault planes or joint planes of rhyolite-tuffs in ill-defined ore bodies. In the Cacária district tinstone occurs in quartz porphyry traversed by a network of small veins; one mine, the Mina del Diablo, seems to consist of a very narrow belt of such rock.

Near the well-known iron mountain of Durango tinstone occurs in rhyolite as at Potrillos, and many of the silver mining districts have yielded small amounts of cassiterite. The association is worth noting, though it seems to be far from being as intimate as it is in Bolivia. No accurate figures are available respecting the output, but this is stated to be under 50 tons per annum.

[1] *Traité des Gîtes minéraux et métallifères*, 1893, ii. p. 349.

[2] *The Mineral Industry for* 1894, p. 480.

[3] W. R. Ingalls, "The Tin Deposits of Durango," *Trans. Amer. Inst. Min. Eng.* 1895.

SOUTH AMERICA.

BRAZIL.

Gold.—Brazil[1] has long been celebrated for its gold mines, which were first extensively worked about the beginning of the last century, and have, in the aggregate, afforded very considerable amounts of that metal. The large quantities of gold produced in Brazil during the eighteenth century were almost exclusively the yield of alluvial washings, principally in the province of Minas Geraës, which have become to a great extent exhausted, so that the gold now produced is almost entirely the result of deep mining in solid rock. Many of the auriferous deposits of Brazil differ essentially in character from those of most other countries, since the gold is often disseminated in metalliferous strata rather than enclosed in auriferous veins. The chief gold mines[2] occur along the chain of the Espinhaço Mountains for a length of 1,200 kilometres.

The richest portion of the province of Minas Geraës is that situated between Congonhas do Campo on the south, Candonga on the north, the tributaries of the Rio Doce on the east, and the Rio das Velhas on the west. The auriferous series is here made up of granite and gneiss, overlain by micaceous and talcose schists with interstratified seams of quartzite, which usually contains either mica or talc. These micaceous rocks are succeeded by clay slate, and often enclose lenticular masses of quartz. The clay slate is followed either by an inconsiderable stratum of granular quartz, or, more frequently, by thin bands of magnetite and specular iron ore alternating with granular quartz. The characteristic gold-bearing rocks of Brazil are known as *itacolumite*, *itabirite* and *jacotinga*.

Itacolumite is a friable sandstone consisting mainly of quartz sand, but containing talc or mica, and sometimes also possessing a certain amount of flexibility when in thin laminæ. *Itabirite* is a mixture of specular iron ore and magnetite with a variable amount of quartz, and is either granular, schistose, or compact. Geologically, it occupies the upper portion of the Archæan forma-

[1] W. J. Henwood, "Metalliferous Deposits," *Trans. Roy. Geol. Soc. of Cornwall*, viii. Penzance, 1871; O. A. Derby, *American Journal of Science*, 1882, p. 178; J. A. Phillips, *The Mining and Metallurgy of Gold and Silver*, London, 1867, p. 80.

[2] *Le Brésil en* 1889, p. 69.

tion. *Jacotinga* consists of micaceous iron ore, brown iron ore, and quartz, the latter usually in a state of granular disintegration. Oxide of manganese, talc, iron pyrites and massive iron glance are its chief accessory minerals. It may possibly be a product of disintegration of itabirite; it often carries gold, generally in fine strings, and is sometimes excessively rich. The granite of Candonga contains gold alloyed with palladium. The slaty ironstones or ferruginous sandstones often assume the form of lenticular beds, of which the central portions occasionally contain flakes and grains of gold, sometimes isolated, but at others connected with one another by threads and filaments of that metal. Towards the edges and sides of these auriferous bunches the particles of gold gradually diminish in size and become less plentiful until the rock at length assumes, in all respects, the appearance and composition of ordinary jacotinga. At Gongo Soco a lenticular mass of itabirite is both enclosed in, and penetrated by, veins of auriferous jacotinga. The gold of this formation is always alloyed with silver and copper, and sometimes also with platinum and palladium. The later metal is characteristic of gold derived from the disintegration of itabirite, when the gold sometimes contains as much as 12 per cent. of palladium.

At Saõ Joaõ d'El Rei there are auriferous deposits which were for many years worked with great profit, the gold having been principally obtained from a conglomerate containing rolled pebbles of itacolumite and of unctuous schists. The celebrated Morro Velho Mine is situated fifty miles south of Ouro Preto in the province of Minas Geraës, and was for a time worked by native miners; but on the failure of the Saõ Joaõ d'El Rei Mines it was purchased by the St. John del Rey Company, and has, for many years, been worked by them with success.

The gold is obtained from a quartz lode enclosed in clay slates, schists and quartzites, which, although irregular, both in direction, dip, and dimensions, is strong, and generally well-defined, its average thickness being about 26 feet. The vein chiefly consists of a mixture of magnetic, arsenical, and common iron pyrites, disseminated in a quartzose gangue, being composed approximately of 40 per cent. of quartz and 60 per cent. of various metallic sulphides, its average yield being 18 gram. to the tonne. The arsenical pyrites carries most of the gold, the smallest grain of which is rarely seen previous to the concentration of the ore. Arsenical, magnetic and ordinary iron pyrites respectively predominate at different points, whilst calc spar, brown spar, and, more rarely, yellow copper ore are also present in the vein, which is not unfrequently traversed by clay slate and barren white quartz. When pyrites is entirely absent, gold in appreciable quantity is rarely present. The richest portion forms a pay chute about 200 metres long, dipping at about 45°, which has been worked to a depth of 600 metres.

The Morro Velho Lode is in some places more cavernous and less close in its texture than in others, but where drusy cavities are plentiful the yield of gold invariably diminishes. The most productive matrix for gold is a compact mixture of quartz and pyrites, enclosing varying quantities of country rock. The great metalliferous deposit, known as the Cachoeira, Bahu and Quebra Panella, is one continuous, but very irregular, vein varying in width from seven to seventy feet, and at one point reaching 100 feet in thickness. The average width of this deposit at a depth of 176 fathoms in the Cachoeira, and of 165 fathoms in the Bahu workings, was 19 feet, and stoping ground extended over a length of about 807 fathoms. There is also a north branch called the Gamba separated from the main deposit by a band of country rock, which, although containing a certain amount of gold, is too poor to admit of being worked at a profit.

The shafts, so-called, as the whole of the lode has been excavated from the surface, are carried down at an inclination of about 45°, and the mineral is brought up by strong kibble-like carriages each holding a ton.

The stamp-mills, as well as all the other machinery, are driven by water-power. The average yield of the ore at Morro Velho has been about 4·333 oitavas[1] of gold alloyed with silver, or as nearly as possible half a troy oz., value 32*s.* 6*d.* per ton; in 1895 it was 13 dwt. to the ton, but fluctuates a good deal.

In 1875 the mines belonging to the St. John del Rey Company produced bullion to the value of £144,072; in 1876 the value of the gold and silver obtained amounted to £247,820, and in 1877 to £176,580. From the fiftieth annual report of this company it would appear that in 1880 they stamped 63,540 tons of ore, and realised a net profit of £63,000.

Work was commenced in the Morro Velho Lode in 1835,[2] and from then up to 1887 the total production was about 50,000 kilogr. of gold.

[1] The gold obtained at Morro Velho is usually alloyed with about 20 per cent. of silver. An oitava is 2 dwt. 7·343 gr. troy.

[2] *Le Brésil en* 1889, Paris, 1889, p. 64.

The Cuyabá Mine, worked by the same company, is a bedded deposit of auriferous pyrites, much poorer than the Morro Velho Lode, since its average is only 5·5 gram. to the tonne. This mine produced 87 kilogr. of gold in 1887. In the twelve months March, 1895, to February, 1896, the St. John del Rey Company [1] raised 72,894 tons of quartz and crushed 58,868 tons, producing 331,271 oitavas, or 38,189 ounces of gold. Deep vertical shafts have been sunk and equipped, and there are 100 stamps at work.

The Santa Barbara Gold Mining Company works the Pary Mine; the deposit here is an intercalated vein running in micaceous and hornblendic schists, with a strike about north and south and a dip to westward at 30° to 40°. Work was commenced in 1862 and up to 1887 the production had been 2,038 kilogr.; in 1887 it was 196 kilogr. The average richness of the ore is about 11 gram. to the tonne.

The Ouro Preto Gold Mining Company owns mines at Passagem, Raposos, Espirito-Santo and Borges, but practically only the first is being worked actively. There is a contact deposit between itabirite on the hanging and mica schist on the foot wall, striking N.E.—S.W. and dipping 20° to the south-east. The width is variable, up to about 16 feet. The gangue consists of quartz and occasionally garnets, and the metallic minerals are iron and arsenical pyrites, magnetic pyrites, galena and bismuth, and of course gold. In the process of amalgamation, an amalgam of bismuth and gold is produced, from which a certain amount of the former metal is always recovered. In November, 1888, there were crushed 1,930 tons of ore, yielding 24·268 kilogr. of gold, besides some bismuth. The production for 1887 was 270 kilogr. of gold. In the year ending June 30th, 1895,[2] this Company obtained the following results:—

Passagem Mine	46,138 tons crushed,	got	16,068 oz.	bar gold	850 per mil.	fine.
Raposos Mine	2,384	,,	,,	325	,,	,, ,,

Total value of gold got £60,097.

The mines of Dom Pedro, North del Rey, Gongo Socco and several others are working on beds of auriferous jacotinga, which is often very rich, *e.g.*, at Gongo Socco from 1826 to 1856 there was produced gold to the value of £6,118,195. At the Maguiré Mine 103 tonnes of jacotinga yielded 124 kilogr. of gold in 1868.

Of the alluvial deposits the best known are the placers on the

[1] *Directors' Report for* 1895.
[2] *Ibid.*

rivers Cabaçal and Coyapó, Barro Alto, &c. The bed rock is generally granite or metamorphic schists, and the placers are generally shallow.

About 1888 the province of Mines Geraës was producing about 2,100 kilogr. of gold per annum; the total production from 1700 to 1888 is estimated at 658,228 kilogr. The production during the same period of the other provinces—Bahia, Maranhão, San Paulo, Parana, Rio Grande do Sul, Matto Grosso and Goyaz—is estimated at twenty millions of pounds sterling.

Soetbeer estimates the value of the gold production of Brazil from the year 1691 to 1875 at £144,668,475; the U.S. Mint Report estimates it at £173,800 during 1893.

Other Metals.—Iron ores[1] abound in almost every part of Brazil, and the deposits which occur in the province of Minas Geraës alone would appear to be almost inexhaustible. In this province a superficial deposit of a clastic iron ore, varying from one to four yards in thickness, extends for a great distance, resting on iron schist, mica schist, talc schist, clay slate, or itacolumite as a bed-rock. This ore is known under the name of *canga* and consists of angular fragments of magnetite, iron slate, iron glance and brown iron stone, together with small quantities of quartzite, itacolumite, and other rocks. The cementing material, which imparts great tenacity to the breccia, is red iron ore, brown iron ore, and yellow and red ochres.

Itabirite[2] often loses its quartzose constituents and then passes into beds of specular ore and hæmatite, containing also magnetite, martite and oxides of manganese. Deposits of these ores, as well as of *canga*, are enormously developed near Ouro Preto. These ores are smelted by the natives to some extent in small fires like Catalan forges, using charcoal as fuel. There are probably a hundred such forges in existence, and about 3,000 tonnes of iron of admirable quality are thus annually produced. At São Paolo lenticular deposits of magnetite occur, the ore from which is treated in a small charcoal blast furnace establishment, belonging to the Government; in 1887 there were 790 tonnes of pig-iron thus produced.

At Santa Catharina there are large deposits of manganiferous hæmatite, averaging 30 per cent. of manganese, and 25 to 30 per cent. of iron; they sometimes pass into pure manganese ores. These latter, both in veins and in irregular deposits, abound in

[1] A. de Bovet, *Ann. des Mines*, iii. 1883, p. 85.
[2] *Le Brésil en* 1889.

many localities; in some swampy districts, deposits of manganite analogous to bog iron ores have been found. A certain amount of high grade manganese ore has recently been shipped to this country from Brazil. Copper ores are known in several places, chiefly in Rio Grande do Sul. Argentiferous galena is also known to occur in several places, as also are ores of antimony and bismuth. No statistics of mineral production are available.

CHILI.

Chili is rich in minerals; and among its metals are gold, silver, copper, lead, antimony, cobalt, nickel, zinc, bismuth, iron, manganese, and quicksilver. Gold is found in quartz veins running nearly north and south, and is accompanied by galena, blende, copper pyrites, iron pyrites and iron glance, but the chief proportion of the gold hitherto produced in Chili has been obtained by washing the beds of rivers.

GOLD.—Andacollo,[1] 40 miles S.E. from Coquimbo, is the chief gold mining district. There are important gravel deposits at this place, which have, however, never been worked on a large scale for want of water, which is scarce. One of these deposits is now being worked by an amalgamation process, yielding about 9 grains of gold to the ton of gravel. The boulders consist chiefly of igneous rocks, whilst pebbles of ilmenite and other oxides of iron, quartz, calcite, iron pyrites, arsenical and copper pyrites, &c., all characteristic of the gold veins of the district, are found in the gravel; the gold is chiefly in the form of dust, nuggets of more than 2 or 3 dwt. in weight being rare.

There are numerous veins, whose general trend is east and west, and whose breadth varies from a few inches to three or four feet. The upper part of the veins is filled with quartz, calcite and oxides of iron, and the gold is free, but at a depth of 100 feet, or sometimes less, a pyritic zone is reached, in which the lode carries much iron, copper and arsenical pyrites, blende, stibnite and galena also occurring. This portion of the vein is usually richer than the upper oxidised part. An average of 250 assays from all parts of the various mines gave about 15 dwt. of gold per ton. It is noticeable that such parts of the veins as contain massive pyrites in quartz are usually richer in gold than those in

[1] The following information has kindly been communicated by Mr. Henry E. Ede, A.Sc., F.G.S.—H. L.

which the quartz and pyrites are so intimately mixed as to form a more or less homogeneous mass. The output of these veins is at present small, being between 25 and 60 kilogr. per annum.

Soetbeer estimates the production of gold in Chili from 1545 to 1875, a period of 330 years, at £36,772,200. In 1893,[1] the export was $636,360[2] (about £100,800) and in 1894 it was $1,211,600 (about £191,850). The total amount exported during the 51 years from 1844 to 1894 is given as $11,150,255 (about £1,765,500).

Silver.—The richest silver mines are found in the Upper Jurassic rocks of the province of Atacama. The most productive districts are Chañarcillo, Tres Puntas, Florida and Caracoles. The lodes of Chañarcillo[3] occur in beds of a bluish limestone of Jurassic age, interstratified with various metamorphosed rocks. The varying nature of the country rock through which the veins descend has a very decided effect on their contents. They run along the side of a short range of hills, and the general direction of their strike is north-east, the dip being north-west. There are, however, lodes which dip to the south-east, but although many of these have been explored to a considerable depth, they have, generally speaking, been found to give unsatisfactory results. The principal lodes at Chañarcillo are four in number, namely, the Veta Colorada, the Veta Cache, the Veta Descubridora, and the Veta Candelaria. The first two run nearly parallel at a distance from one another varying from actual contact to fourteen yards, the Veta Cache being the more irregular vein of the two. These lodes have a strike of 20° E. of N., and the Veta Descubridora has a similar direction, whilst the Veta Candelaria courses 45° E. of N., cutting through the other three lodes, but the points of intersection do not, as a rule, show any increase of richness. These veins, which have been traced for a distance of a mile and a half, are accompanied by others of a secondary character, and these by still smaller ones, which are nevertheless of considerable importance. The lodes are much affected by the nature of the enclosing rock. They become narrower in unfavourable rocks, but, in those of a contrary nature, the lodes become not only wider and richer, but the walls also

[1] *Estadistica Comercial de la Republica de Chile, año de* 1894.

[2] The Chilian *peso* is worth 38 pence.

[3] For particulars relative to the mines of Chañarcillo, Rosario, Panulcillo, and Carrizal Alto, I am indebted to Mr. M. H. Gray, A.R.S.M., who kindly placed at my disposal his notes on the metalliferous deposits of Chili, made during his visit to that country.—J. A. P.

become impregnated with ore to such an extent as to allow of their being profitably worked for a distance of sometimes nine feet from the lodes. According to Mr. Gray, the Chañarcillo lodes traverse various beds of rock occurring in the following order :—

Class of Rock.	Thickness.	Contents of Lodes.
1. Stratified calcareous rocks . .	660 feet	Iodide, chloride, and native silver.
2. Intrusive rock	330 ,,	Narrow lodes, calc spar. No silver ore.
3. Carboniferous limestone . . .	80 ,,	Argentite, ruby silver and native silver.
4. Metamorphosed and siliceous strata	400 ,,	Dead ground, except a layer of 35 ft. in centre of strata, making rich in silver ore in the Bocona Mine alone.
5. Calciferous bituminous strata .	330 ,,	Native silver, antimonial ores, arsenides, and sulphides.
6. Metamorphosed rocks	660 ,,	Dead ground.
7. Calciferous strata	unknown.	Arsenides and sulphides of silver.

From the surface for some distance downwards the lodes are filled with a soft clayey material, containing iron ochre, calc spar, heavy spar, malachite, and native silver, together with chloride, iodide, and bromide of silver, *metales calidos*. Occasionally small fragments of undecomposed sulphuretted ores are met with in these gossans. At a depth varying from thirty-five to eighty-five fathoms, the *metales calidos* disappear, and in their place *metales frios*, consisting of silver glance, polybasite, pyrargyrite, blende and galena, make their appearance ; but iron pyrites is of somewhat rare occurrence.

At Caracoles, on the frontier of Bolivia, the Upper Jurassic limestones and marls are traversed by quartz-porphyries and compact greenstones, the lodes, from eighteen inches to fourteen feet in width, being generally productive in the porphyry. They usually contain native silver, with the chloride, bromide and iodide of that metal, whilst the gangues vary in the different lodes, some consisting of calcite, gypsum, heavy spar, hornstone, and decomposed porphyry, others of quartz and heavy spar, whilst a few consist of heavy spar only.

At Arqueros, in the province of Coquimbo, heavy spar lodes, rich in silver, occur in Jurassic limestones traversed by porphyries. The ores consist of native amalgam, native silver, antimonial silver, silver chloride, stephanite, speiss cobalt, fahlerz, erubescite, and copper pyrites. The bulk of the silver exported from Chili is as smelted metal, a much smaller amount being shipped in the form of ore, regulus and argentiferous lead. The total quantity of fine metal was 164,871 kilogr. in 1893 and 179,835 kilogr. in 1894[1]. The total exportation in the 51 years from 1844 to 1894 has been about 3,684 tonnes in the form of metal, together with a small amount in other shapes.

Copper.—Although the amount of silver raised in Chili is very considerable, copper is, nevertheless, the most important product of the country. The principal copper mines are situated in the provinces of Atacama, Coquimbo and Aconcagua, and the most important are those of San Juan and Carrizal near Copiapo, La Higuera near Coquimbo, and Tamaya, about sixty-five miles from Coquimbo, situated in an elevated mountain district.

At the Rosario copper mine, situated 2,680 feet above sea level, there are two main lodes running parallel to one another, and only a short distance apart. The more regular of the two is the Veta Negra, which lies on the foot wall side, striking 10° W. of N. and dipping S. of W. The Veta Verde is on the hanging wall side and, although irregular, considerably resembles the Veta Negra both in strike and dip. There is also a lesser vein joining the other two, their junction being very rich; both veins are intersected by cross-courses. The breadth of the lodes varies from one up to fourteen fathoms, the latter width being only attained where the three veins come together. The Veta Verde, undulating upon the Veta Negra, has produced many rich bunches at the points of junction. The gangue is almost entirely felspathic with a little hornblende and calc spar, whilst the walls are of diorite in which epidote and magnetite are accessory constituents.[2]

There are carbonates and silicates of copper near the surface, especially on the Veta Verde, but these do not extend to any considerable depth. Then follows purple ore, but the principal part of the mine is worked on yellow copper pyrites, the lowest workings being at a depth of over 300 fathoms. The Panulcillo copper mine is forty-five miles from Coquimbo, the ore being obtained from a contact deposit and not from a true vein. The ore-bearing ground is divided into two parts by a cross-course, and the two divisions are worked separately, being respectively known as the North and South Mines. These ore masses strike 5° W. of N. In the North Mine the deposit goes down perpendicularly, but in the South Mine it dips 63° E., the cross-course striking

[1] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. 71.

[2] J. Lipken, *Berg. und Hüttenm. Zeit.* 1877, p. 129.

45° E. of N. The North Mine deposit has a length of 900 feet along the strike, and the widest part yet opened measures seventy feet, the narrowest stope being about forty feet across. The east side is composed of stuff too poor to work. The western wall is of porphyry and has a good selvage, whilst the eastern is composed of mica schist and is rather indefinite. The ore is copper pyrites, with a gaugue of crystalline tourmaline. The deposit at the South Mine is 600 feet long, and fifty feet across in its widest part. The eastern wall of this lode is of mica schist, and the western wall of crystalline limestone containing crystals of mica. The ore and gangue are of the same character as those in the North Mine.

Carrizal Alto was once a very important copper-mining district but is now decidedly on the decline, the copper at present produced coming from ground already worked over. The lodes of this district, which run more or less parallel to one another with a north-north-east direction, are frequently crossed by igneous dykes, and are usually enriched where so intersected. As a general rule, from the outcrop to a depth of twenty-five fathoms the ores are carbonates; for the next ten fathoms friable melaconite is met with; whilst below this comes yellow copper pyrites with iron pyrites to a depth of 240 fathoms. After this so far as has hitherto been explored, dead ground prevails. Many other important copper mines are worked at various places in the Northern Provinces.

The copper exported from Chili during the year 1881 amounted to 38,030 tons and in 1882 to 42,960 tons. These figures represent fine copper, and therefore include the metal contained in both ore and regulus. Of the total amount of copper exported from Chili during 1882, 84 per cent. was in the metallic state, 14 per cent. as regulus, and about 2 per cent. in the form of ore. In 1893[1] the total amount of fine metal exported was 23,033 tonnes, and in 1894 it was 23,197 tonnes; of the latter total, 84 per cent. was as metal, 12 per cent. as ore, and 4 per cent. as matte. The total exportation since 1844 is over a million tons as bar copper, and about one-third more in the form of ore and matte.

In Chili the most common ore of cobalt is arsenical cobalt, and the most important lode is the Veta Blanca of San Juan; glance cobalt, and erythrite are also worked at Tambillos and at Huasco.

[1] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. 69.

MANGANESE.—Manganese[1] is being extensively mined in two districts lying inland from Coquimbo and Carrizal respectively. The ore occurs in beds interstratified with sandstones, clays, shales, calcareous rock and gypsum, of Cretaceo-Oolitic age.

The beds of ore are never very uniform for any great distance, split up, thin out, and come in again irregularly, are much faulted, and associated with eruptive masses and overflows of igneous rocks. A section through the Cocinera Mine, Fig. 128, illustrates one form in which the deposit occurs. The ore consists of peroxide and protoxide and some silicate of manganese, together with silica, lime, baryta, &c.; metallic manganese averages about 50 per cent., and the phosphorus contents are very low. The Chilian Manganese Mining Company, Limited, controls the principal mines; its production is derived about equally from the

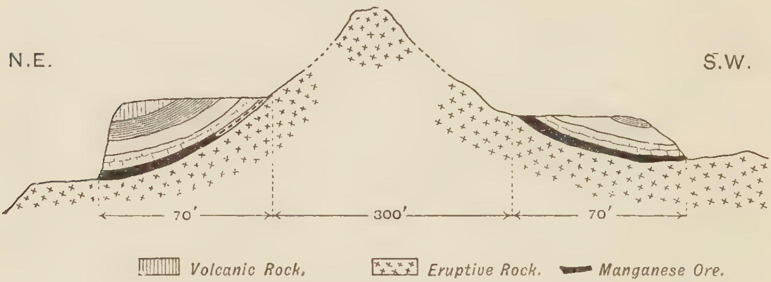


FIG. 128.—Section through the Cocinera Manganese Mine.

Southern or Coquimbo, and the Northern or Carrizal group, and amounts to about 20,000 tons per annum.

The total yearly production of Chili may be estimated at above 30,000 tons of manganese ore. In 1894 the exports[2] of manganese ore are given as 47,994 tonnes, as against 36,741 tonnes in 1893. The total exports since the beginning of 1884 amount to 351,792 tonnes.

The following table[3] of the mineral production of Chili for the first half-year of 1895 will give an idea of the importance of this country as a mineral producer:—

[1] From information kindly supplied by Mr. Henry E. Ede.

[2] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. 443.

[3] *Boletin de la Sociedad Nacional de Mineria*, Santiago de Chile, Nov. 1895, p. 210.

Table showing the Production of Metals and Metallic Minerals in Chili for the First Six Months of 1895.

Substance.	Weight.	Values. $1	Values. £
Gold	644·5 kilogr.	515,608	81,638
Silver	61,672 ,,	1,541,236	244,029
Copper	10,425 tonnes	2,293,597	363,153
Copper matte	1,702 ,,	170,230	26,953
Silver and Copper matte	217 ,,	43,461	6,881
Silver, Gold and Copper matte	24 ,,	4,762	754
Copper ores	5,054 ,,	202,160	32,009
Silver and Copper ores	70 ,,	10,462	1,657
Silver, Gold and Copper ores	2 ,,	384	61
Iron ores	305 ,,	3,048	483
Manganese ores	11,267 ,,	112,672	17,840
Gold ores	904 ,,	226,062	35,793
Silver ores	242 ,,	130,637	20,684
Silver-gold ores	69 ,,	17,166	2,718
Sulphuretted silver ores	34 ,,	128,781	20,390
Silver-lead ores	510 ,,	76,434	12,101
Total values		5,476,700	867,144

These figures may be compared with the following, giving the exports of metallic minerals from Chili for the entire year of 1895.[2] It must not be forgotten that the main mineral product of Chili is not metallic, being nitrate of soda, of which there were exported in the year in question 1,220,000 tons, worth about £7,437,000.

Table showing the Exports of Metallic Minerals from Chili during 1895.

Substance.	Weight.	Values. $1	Values. £
Gold	1,184·5 kilogr.	947,794	150,067
Bar silver	148,747 ,,	3,867,412	612,340
Ingot copper	20,042 tonnes	4,602,114	728,668
Copper and silver mattes	649 ,,	131,364	20,799
Silver ores	2,137 ,,	1,051,034	166,414
Sulphuretted silver ores	99 ,,	123,155	19,500
Copper ores	6,963 ,,	278,515	44,098
Manganese ores	24,075 ,,	241,383	38,219
Total value of exports		11,242,771	1,780,105

1 Values in Chilian *pesos* worth 38*d*.

2 *Boletin de la Sociedad de Fomento Fabril*, Santiago de Chile, xiii. 1896. No. 3, p. 74.

BOLIVIA.

The great extent and variety of the mineral productions of Bolivia have given it an importance which it could not otherwise have possessed. Gold is found in considerable quantities in the mountainous parts of the country, and occurs in lodes in association with silver and other ores. The greater portion of this metal is, however, obtained from washings in the beds of rivers. Several districts in Potosi, Chuquisaca, Santa Cruz and Tarija are auriferous. The production of gold in Bolivia in the year 1881 was, according to Burchard, about 3,500 oz. In 1893, according to the United States Mint report, it was £13,400.

SILVER.—Silver is, however, the staple metallic production of Bolivia, the mines of Potosi[1] being well known for their almost fabulous riches. They were discovered in 1545, and their annual production was estimated by Chevalier in 1845 at from 48,000 to 60,000 lbs. troy. The celebrated mountain of Potosi rises 2,697 feet above the great square of the city of that name, which is situated at its base. It has a somewhat conical form, and consists, from the summit to a depth of about 200 fathoms, of quartz-porphyry. From this point clay slate forms a mantle round the porphyry. The labour of the miners has been confined to the upper portion, where about sixty lodes, coursing N.E. and dipping from 65° to 70° S.E., together with various workable strings of ore, traverse the porphyry. The lodes continue down into the deeper parts of the mountain, sometimes passing out of the porphyry into clay slate, in which, however, they become less productive. The minerals contained in the lodes are quartz, iron pyrites, pyrargyrite, fahlerz, cassiterite and silver chloride, together with native silver.

The silver mines in the province of Chicas have acquired considerable celebrity on account of the richness and quantity of their ores. The once famous mines in La Paz are now abandoned, whilst those of Arque, Lipez, and of the department of Oruro, are not regularly worked. In the last-named district a porphyry dyke has burst through the clay slate, and is traversed by numerous lodes coursing N.E. and dipping from 45° to 85° N.W., with a thickness varying from three inches to several yards. The vein stuff consists principally of porphyry impregnated with iron

[1] H. Reck, *Berg und Hüttenm. Zeit.* 1858, p. 275; *ibid.* 1866, p. 389.

pyrites. Pyrargyrite, stephanite, plumosite, antimonial glance, argentiferous fahlerz and cassiterite occur in strings. Near the surface *pacos* ores are found, whilst lower down *mulatos* and *negrillos* make their appearance.[1] In 1870 silver deposits were discovered at Caracoles, in the desert of Atacama. Burchard states that in 1881 the silver production of Bolivia amounted in value to $11,000,000. In 1893 it was $15,488,000, according to the United States Mint report. In 1894[2] there were exported from Antofagasta in Chili, 311,682 kilogr. of silver in bars, about 10,500 tonnes of various kinds of silver ore, and 29 tonnes of pig lead, all of which were produced in Bolivia.

COPPER.—Copper takes the next rank among the valuable metals of Bolivia, and occurs in the departments of La Paz, Potosi, Chuquisaca, Oruro and Beni. At Algodon Bay, in the vicinity of the desert of Atacama, lodes from three to six feet in thickness occur in diorite and syenite, and contain copper glance together with copper pyrites. They also contain atacamite, but azurite and malachite are never met with; the Atacamita Lode is especially rich in atacamite, which occurs mixed with red copper ore.

The value of the copper exports from Bolivia to the United Kingdom during the year 1882 was as follows:—

Ore	£46,794
Regulus	80,391
	£127.185

Its production in 1894 is given as 2,300[3] statute tons of metal.

TIN.—Tin has been produced in considerable quantity in Bolivia in recent years. It occurs throughout a vast district extending from Huancane,[4] in Peru, to Chocaya, in Bolivia, from 15° to 21° south. The ore is cryptocrystalline cassiterite, accompanied by tin pyrites, silver ores, fahlore, iron pyrites, blende, galena, &c., the vein-stuff consisting of quartz, barytes and various carbonates. The paragenesis is thus utterly different from that of all other known occurrences of tin-stone, such minerals as tourmaline, topaz, fluor spar and apatite being conspicuously absent. The tin ore is so intimately associated with the above-named minerals that it

[1] H. Reck, *Berg. und Hüttenm. Zeit.* 1868, p. 77.
[2] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. xxvii.
[3] *The Mineral Industry*, iii. 1894, p. 163.
[4] A. W. Stelzner, *Zeitschrift. f. Prakt. Geologie*, 1893, p. 81.

seems necessary to believe that their formation must have been simultaneous; so close is the mixture that many of the ores have first to be amalgamated to extract the silver and then the residue smelted for tin. It is noteworthy that the upper portion of the vein is the richest in cassiterite, this mineral being gradually replaced by argentiferous sulphides with increasing depth, so that these veins may be spoken of as carrying a stanniferous gossan. In the Cerro de Potosi certain veins were very rich in tin at their outcrops, whilst at depths of 180 metres below the surface the ores were argentiferous copper and iron sulphides with only 0·7 to 1·5 per cent. of tin. The rare mineral franckite, a fahlore containing tin and germanium, is found in these veins.

The occurrence of these veins is closely associated with certain eruptive rocks, chiefly trachyte and andesite.

The output of tin is important; the exports[1] to England were 2,909 tons in 1893, and 3,482 in 1894.

The export of tin through Antofogasta[2] in 1894 was:

	Tonnes.
Tin ore (concentrates) . . .	3,553
Bar tin	1,875

These concentrates,[3] known as *barilla*, are said to average 80 per cent. metal (?), which, if correct, would make the total production equal to 4,717 tonnes of metal. The Potosi mines are said to have shipped 1,965 short tons nearly all bar tin, and the Quechisla mines 124 short tons of bar tin and 530 short tons of concentrates in that year.

OTHER METALS.—Cinnabar and ores of lead occur in some places, but are very little worked at present. Bismuth is produced in considerable quantity; the Quechisla[4] mines are said to have produced 401,562 lbs. in 1894. The export through Antofagasta[5] is returned at 196,434 kilogr. (433,063 lbs.).

No statistics of production are available, but the following figures show the export during the year 1894 of minerals produced in Bolivia, from the Chilian port of Antofagasta, through which the

[1] *First Annual General Report upon the Mineral Industry of the United Kingdom for* 1894, p. 53.

[2] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. xxvii.

[3] *The Mineral Industry*, iii. 1894, p. 528.

[4] *Ibid.*

[5] *Estadistica Comercial de la Republica de Chile, año de* 1894, p. xxvii.

great majority if not the whole of the produce of Bolivia finds its way to the various markets of the world :—[1]

Table of Bolivian Exports of Metallic Minerals during 1894.

Substance.	Weight.		Values.	
			$[2]	£
Bar silver	311,692	kilogr.	12,466,510	1,973,864
Silver residues	691	,,	345	55
Sulphuretted silver ores .	3·7	tonnes	7,402	1,172
Argentiferous pig lead .	29·2	,,	2,920	462
Silver ores	10,411	,,	3,123,389	494,536
Silver-lead ores	92	,,	18,410	2,914
Antimony ores	3,075	,,	307,535	48,694
Tin concentrates (*barilla*)	3,553	,,	1,421,069	225,002
Bar tin	1,875	,,	1,124,790	178,091
Bismuth	196	,,	392,868	62,206
Total value of exports			18,865,238	2,986,996

PERU.

Peru has long been famous for its wealth of silver and gold. Soetbeer estimates the amount of gold produced during the years 1851 to 1875 at 20,570 lbs., worth £1,304,325. The total export of gold from Peruvian ports during the year 1877 amounted to 35,633 oz.

Silver.—Silver is, however, more widely distributed over the country than is gold. The silver mines of Huantajaya, Pasco and Chota are remarkably rich, and great improvements in the system of mining were introduced into this district by the celebrated Richard Trevithick.

The mines of Cerro de Pasco are perhaps the most remarkable, and may be taken as a type of the others. Among the principal ores are the so-called *pacos*, the *colorados* of the Mexican miners, which are ferruginous earths mixed with silver ores resulting from the decomposition of argentiferous sulphides. De Rivero[3] considers the Santa Rosa deposit not to be a true vein, since it is parallel with the formation. The hanging and foot walls are of a different character, and the gangue has no crystalline comby structure.

[1] *Boletin de la Sociedad de Fomento Fabril*, Santiago de Chile, xiii. 1896. No. 3, p. 74.

[2] The values are in Chilian *pesos*, worth 38*d*.

[3] *Ann. des Mines*, ii. 1832, p. 169.

According to A. D. Hodges[1] the silver-bearing rock consists of slates, sandstones, and limestones, tilted up at a steep angle by the eruption of a huge mass of andesite; these stratified rocks have been metamorphosed by the action of the mineralising solution, and appear to have had masses of pyrites associated with argentiferous minerals deposited in them, or to be impregnated by the same; in the upper parts of the deposit there are a number of secondary minerals that may be the result of the action of meteoric waters upon the pyritic minerals, and which contain a large proportion of native silver. The foot wall of the deposit consists of the above-mentioned andesite, the hanging wall of a bed of unconformable limestone. At the present day very little mining is done here, the operations being chiefly confined to the re-working of old slags, residues, *débris*, &c. From these sources about 34,000 kilogr. of silver are obtained yearly.[2] The mines of Pasco were discovered by accident in 1630, and are still comparatively important. Their production was, in 1870 to 1875, 1,241,888 marks; in 1876, 169,849 marks, and in 1877, 178,469 marks, the mark being 230·046 grammes. The annual production of silver in Peru was estimated about 1880 at some 345,000 marks.[3] The United States Mint Report estimates the output in 1893 at $2,402,700, and the gold production at $73,000. In 1888[4] the total silver production of Peru was estimated at 120,000 kilogr. The silver ores of the north, and more particularly those of Scalpi, generally contain gold. These ores are for the most part sent for treatment to Swansea, and a small portion to Freiberg and Clausthal.

Other Metals.—Ores of mercury are widely distributed, and are said to have been known to the inhabitants before the invasion of the country by Europeans. The deposits of Huancavelica were the most important, and have been worked since 1566, but are now abandoned; the cinnabar is found in Carboniferous sandstones and clay slates, and is very similar in its mode of occurrence to that of Almaden. Crosnier,[5] who went out for the Peruvian Government in 1851, reports that these quicksilver deposits have nothing in common with true veins, but everything appears to indicate that

[1] "Topography and Geology of the Cerro de Pasco, Peru," *Trans. Amer. Inst. Min. Eng.* xvi. 1888, p. 729.

[2] Alejandro de Ydiaquez, *Le Perou en* 1889, p. 139.

[3] *Report of the Director of the Mint upon the Production of Precious Metals in the U.S.* 1882, p. 535.

[4] Alejandro de Ydiaquez, *Le Perou en* 1889, p. 139.

[5] *Ann. des Mines*, ii. 1852, p. 1.

the ore was introduced in a state of vapour at the time the strata were elevated to their present almost vertical position.

Copper is of frequent occurrence in Peru, but lead and iron ores, although plentiful, are not worked. The province of Ica,[1] one of the main sources of the Peruvian copper output, produced 1,337 tonnes of copper in 1884, but the production appears to have diminished since then. No statistics seem to be obtainable.

GUIANA, &c.

The vast territory of Guiana has been divided into Brazilian Guiana, Venezuelan Guiana, and Colonial Guiana. The first two divisions, comprising five-sixths of the entire region, are now included in Brazil and Venezuela respectively, whilst the last division is composed of the territories of British, Dutch, and French Guiana. Over the whole of this large country gold is found both in placers and *in situ*, and there can be no doubt that a great South American gold-field is capable of being developed which might play an important part in the world's gold supply, although its growth is retarded by the various political complications and the known unhealthiness of the region.

Venezuelan Guiana.[2]—The most important mine of Venezuelan Guiana is El Callao, which could claim to be ranked among the richest gold mines of the world. The workings were about sixty fathoms in depth, the lode varying from four to seven feet in width, with an underlie of 52°. Generally the quartz is white, but occasionally it is tinged greenish by a chloritic mineral; it contains much free gold with but a small amount of sulphides. According to Dr. Foster, the Callao Lode courses north and south and dips west, the country rock being felstone with a little iron pyrites. The miners consider the presence of iron pyrites a favourable sign with regard to the productiveness of the lode. The lode had, in 1869, been worked for a distance of 100 fathoms along the strike, and is said to die out southwards. From 1871 to 1879, a total quantity of 67,362 tons of quartz was crushed, from which 252,973 oz. of gold were extracted. In 1880 the Callao Company's mines crushed 18,624 tons of quartz, giving 54,013 oz. of melted gold, worth £205,969. After a brilliant career, this important mine was

[1] Alejandro de Ydiaquez, *Le Perou en* 1889, p. 139.

[2] C. Le Neve Foster, "On the Caratal Gold-field," *Quart. Jour. Geol. Soc.* xxv. 1869, p. 236; "Concession relating to the State of Guiana, South America, and Reports on its Produce, Gold-fields, &c.," London, 1882.

no longer able to pay expenses in 1895, and was then on the point of finally closing down. A total quantity of 719,257 tons of quartz had been extracted from it, which yielded 1,438,638 oz. of gold, or at the rate of 2 oz. to the ton; of the amount thus realised, over one-third was returned in dividends to the shareholders. The production of this company was as follows in 1895 [1]:—

Mine.	Tons crushed.	Gold produced. Oz.
El Callao, Remington	10,937	5,300·19
Colombia	36,519	15,335·93
Nueva, Panama	9,829	3,864·95
	57,285	24,501·07

The Chile Lode is probably, after Callao, the most important in the Caratal district. The main lode courses E. 10° N., dips 45° to 60° S., and varies from two to six feet in width. It consists mainly of quartz with brown oxide of iron, chlorite, talc, a white earthy mineral like kaolin, and visible gold. The country rock is composed of talcose clay slate, and a ferruginous hornstone also frequently occurs. The latter rock, called "porphyry" by the miners, is regarded as a favourable indication for gold. The Chile Company's mines in 1880 crushed 6,762 tons of quartz, giving 14,525 oz. of melted gold with a fineness of 912. The Potosi mines produced, in 1880, 23,280 oz. of gold, worth £90,210.

Gold mining, which is the chief and almost the only industry of the Caratal district in Yuruari, dates from 1866, since which time to December, 1879, a total of 770,026 oz. had been shipped at the port of Ciudad Bolivar, the amount shipped in 1879 being 107,722 oz. Practically all the important mines are in the Yuruari territory, the production of which was as follows in the year 1888:—[2]

	Kilogr.
El Callao	1,644
Chile	70
La Union	196
El Callao Bis	21
El Choco	3
Venezuela Austin Co. Limited	154
Various other Companies	186
Surface gold, &c.	70
Total for 1888	2,344

[1] *Report of the Directors, April*, 1896.

[2] *Statistical Annuary of the United States of Venezuela for* 1889.

From 1866 up to 1886 the gold exported from the territory of Yuruari was 55,862 kilogr. The greater part of the mines started in this field seem not to have proved valuable in depth, and there is but little mining being done in 1896. The gold output has accordingly diminished considerably and is now relatively small. The gold output of Venezuela is given as 39,000 oz. in 1894.[1]

There are important mines of copper at Aroa in the State of Lara, worked by the Quebrada Copper Company, the ores sent to this country being chiefly gossans of brown hæmatite carrying carbonates and other oxidised ores of copper. In the years 1886–1888 the output was 72,610 tonnes of ore. The total production in 1894 [2] is estimated at 2,500 tons of metal.

Dutch Guiana.—Gold digging commenced here in 1875, and the development of this branch of industry has since greatly increased. The production in 1879 was 679,914 florins. It is practically all obtained from shallow placers, the production for 1894 being given as 872 kilogr.,[3] worth $579,600.

French Guiana.—Indian tradition long ago affirmed the presence of gold in French Guiana, and both Humboldt and Buffon were of opinion that the geological character of the country rendered its presence probable. The diggings of Pastroptôt, in the district of Mana, produced 300 lbs. of gold during the first six months of 1879. The auriferous bed is composed of quartz fragments resting on clay, with a covering of fine sand. There is no doubt that rich quartz veins, as well as placers of apparently abnormal richness, exist in the district of La Mana, but the nature of the country offers serious, if not perhaps insuperable, obstacles to systematic mining. A French Company attempted to work a concession in this district, but after struggling on for a good many years was compelled to suspend operations. Statistics of total production are not available, but in 1894 the quantity of 4,836 kilogr.,[4] valued at £540,000 was declared for export at the customs; how much more was produced cannot be said.

British Guiana.—This colony is known to be very rich in gold; rich gold quartz has been found in many places, notably on the Essequebo,[5] Cuyuni and Barima rivers. Quartz veins occur mostly in metamorphic schists and gneiss, and nearly all the

[1] *The Mineral Industry*, iii. 1894, p. 286.

[2] *Ibid.* p. 163.

[3] *Ibid.* p. 285.

[4] *Statistique de l'Industrie minérale en France*, 1894, p. 59.

[5] H. J. Perkins, *Notes on British Guiana and its Gold Industry*, 1895, p. 4.

streams and rivers that traverse regions occupied by the above rocks or by granite, are gold-bearing; ores of silver, lead and copper have been found, but gold is the only metal worked, and almost exclusively from shallow placer deposits, reef mining having been neglected up to the present. The production of the chief alluvial districts in 1895 was as follows:—

Cuyuni	28,753 ounces.
Barima	27,953 „
Essequebo . . .	27,206 „
Potaro	25,614 „

The following table, taken from official sources, shows the total gold production since the year 1884:—

Gold Production of British Guiana from the Year 1884 to 1895 inclusive.

Year.	Production.	Year.	Production.
	Oz.		Oz.
1884	250	1890	66,864
1885	939	1891	110,556
1886	6,518	1892	138,276
1887	10,987	1893	137,817
1888	20,216	1894	128,756
1889	32,333	1895	122,933
Total for 12 years			776,445

United States of Colombia.—The United States of Colombia have been long known as a gold-producing country, gold mining having been commenced by the Spaniards in 1537. Soetbeer estimates its total production up to the end of 1848 as $682,000,000. The annual production is now about $4,000,000, having been £850,000 in 1891. The gold of Giron is of exceptional purity, as its fineness often reaches twenty-three and a half carats. The production of silver in 1880 amounted to $1,000,000. The Department of Antioquia[1] is the most productive of the State, some large gold mines being at work there, and hydraulic mining being carried on on a large scale; its production in 1890 was estimated at $2,800,000. The Department of the Cauca, and especially the valley of the Choco, is very rich in gold, but the

[1] "The Mineral Wealth of Colombia," *The Mining Journal*, Aug. 18, 1894, p. 901.

deadly nature of the climate and the difficulty of access have retarded the development of this region. Its production is given as almost equal to that of Antioquia. The Department of Tolima also produces much gold, chiefly from the alluvial deposits of the valley of the Magdalena.

The valley of the Telembi (Barbacoas) also contains many rich placers, the gold being generally very fine. This gold generally carries also small scales of platinum, of which metal a good deal is annually obtained both here and in the Cauca valley, in the districts chiefly of San Juan and of the Atrato River; the annual production is worth about $50,000. Several silver mines exist, the richest being in Mermato and Supia; it is estimated that the entire silver output up to the end of 1890 was $18,000,000.

The production of the great gold-field of South America, north of the River Amazon, was as follows about 1880:—[1]

U.S. of Colombia,	1880	$4,000,000
Venezuelan Guiana	„	2,200,000
Dutch Guiana,	1879	272,000
French Guiana	„	200,000
	Total .	$6,672,000

The outputs of each individual State for recent years have already been given.

Argentine Republic.—It is stated by Mr. Rickard, that at the period of his writing (1863) there were twenty-eight gold mines, the same number of placer washings, forty-six silver mines and eleven copper mines working in the Republic, producing 3,654 oz. of gold, 418,201 oz. of silver, and 15,032 cwts. of copper.[2] Clarence King estimates the production of the precious metals in the Argentine Republic during the year 1880 as: gold $78,546, silver $420,225.[3]

Among the more important mines are those in the province of Rioja, where the formation is Silurian. The copper ores of this region always contain both gold and silver, whilst auriferous veins of quartz are of not unfrequent occurrence.

Some of the most important gold mines are situated in the province of San Luis, the best known perhaps being the Carolina

[1] *Report of the Director of the Mint upon the Production of Precious Metals in the U.S.* 1882, p. 543.

[2] F. Rickard, *Mineral Resources of the Argentine Republic*, London, 1870.

[3] C. King, *Production of the Precious Metals*, 1881.

Mine, which has been worked by an English company. The country formation consists here (as in most of the provinces traversed by the Andes) of metamorphic rocks, chiefly gneiss, mica schists, &c., with granitic, porphyritic and trachytic intrusions. If the statements in the official[1] description can be relied on, the gold does not occur in veins, but in altered beds of conglomerate and clay slate, carrying gold, auriferous pyrites, galena, blende, &c. The general strike is said to be about north and south. It is said that during 1887 there were extracted from the Carolina Mine 1,490 tons of ore, which produced 1,801 oz. of gold. Other mines occur in the same district, which seem to be situated on a continuation of the above-named formation. The Mine Fortuna or Santa Barbara contains a vein about two feet thick, running east and west and dipping to the south between walls of granite and gneiss. The gangue is quartz, carrying chiefly galena, copper and other pyrites, &c., and is said to be rich in gold. Gold-bearing placers are worked in the Cañada Honda, and along the Rio de la Carpa, as well as in several other places. Many other districts and provinces are known to be rich in mines of gold and silver, as well as of other metals, but very little true mining has yet been done. Reliable statistics are not obtainable; in the U.S. Mint report for 1894, the output for 1893 is given as: gold 211 kilogr., worth $140,200; silver 22,026 kilogr., worth $915,400.

Patagonia.—Patagonia and Tierra del Fuego are both known to contain extensive and rich gold placers, though no definite information is available about them. On the sea beach, not far from Punta Arenas, a deposit of black iron sand, probably ilmenite and magnetite, very rich in gold, is known; it is, however, covered at high tide, and the difficulties of working it are enormous. Large tracts of the sea-shore are said to be gold-bearing, and placers are also said to exist in many of the valleys. No precise information is, however, available.

Ecuador.—Gold is known to occur in various parts of this republic. In the Zaruma district small veins of gold quartz superficially very rich, but generally poor in depth, occur in metamorphic rocks. Alluvial deposits are also said to exist in the Playa del Oro. Other metals also occur, notably mercury, but are not worked. The production for 1893 is given in the U.S. Mint report as: gold 79 kilogr., worth $52,000, and silver 240 kilogr., worth $10,000

[1] H. D. Hoskold, *Mémoire Général et spécial sur les mines, etc., dans la République Argentine*, 1889, p. 252.

CENTRAL AMERICA.

That portion of the great mountain range that practically traverses the Americas from north to south, and which seems throughout its course to be productive of precious metals, no doubt must be as rich where it traverses Central America as it is to the north and to the south thereof. It has, however, been but imperfectly explored; work can only be carried on with the greatest difficulty, and its actual production of metallic minerals is far less than it might be. Although great quantities of silver were at one time produced in this region, and though ores of quicksilver, tin, copper, lead, &c., are known to exist, gold is practically the only metal mined for. Placers are chiefly exploited, but some reef mining is also carried on, though but little is known concerning the nature of the deposits. The best known mine is, perhaps, the Rosario Mine, in Honduras, which has been working steadily for a good many years. In Nicaragua the Chontales district is the richest; no statistics are available, but it would seem from some unofficial figures that the production of alluvial gold must be about 8,000 oz., and of reef gold about 16,000 oz. per annum.[1] In Costa Rica much placer gold is got, but the best known mines are those of the Monte del Aguacate, which are said to have produced $7,000,000[2] up to the end of 1892. In Guatemala there are gold placers on the banks of the Motagua, and silver mines in the departments of Santa Rosa and Chiquimula. The total gold production of Central America is given as $470,500[3] for 1894, but no reliance can be placed on the correctness of this figure.

Cuba.—This island contains important deposits of copper, iron and manganese ores, but, owing to its disturbed political condition, very little mining is carried on. The principal iron mines are the Juragua Mines; their production, after having been over 300,000 tons yearly, was only 164,416 tons in 1894.[4] Numerous manganese[5] mines are known in the mountain range between Santiago de Cuba and Manzanillo, the output for 1893 being given as close on 14,000 tons.

1 "Nicaragua," *Bulletin No.* 51, Washington, 1892, p. 163.

2 J. B. Calvo, *The Republic of Costa Rica*, 1893, p. 19.

3 *The Mineral Industry*, iii. 1894, p. 283.

4 *Ibid.* p. 358.

5 *Ibid.* p. 449.

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THE END.

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